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SCIENCE SERVICES DIVISION

TEXAS INSTRUMENTS INCORPORATED

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ARPA Order 624
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VT/6704

CUMBERLAND PLATEAU OBSERVATORY

ANNUAL REPORT NO. 2

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ABSTRACT

Under AFTAC Project VT/6704 Texas Instruments Incorporated has had overall responsibility for the operation of the Cumberland Plateau Observatory during the period May 1966 through April 1967. Work under this project has been a continuation of the previous years effect under Project VT/5054 and has been primarily directed toward improving the use of small diameter seismic arrays in the teleseismic event detection problem. During this last year the feasibility and effectiveness of on-line automatic detection processing was investigated through the evaluation of the CPO Auxiliary Processor. This unit - a digital computing device fabricated during late 1966 - interfaces with the CPO processor. Other tasks included the continued evaluation of the MCF processor to determine the impact of Wiener signal extraction processing on the station detection capability, the continued multidimensional analysis of the CPO ambient noise field to verify noise properties affecting performance of the MCF processor, and the investigation of techniques designed to enhance visual presentation of seismic data.

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SECTION I
INTRODUCTION

Since May 1965, Texas Instruments Incorporated has had overall responsibility for operation of the Cumberland Plateau Seismological Observatory (CPO). In conjunction with this operation, TI has conducted research directed toward the development and application of sophisticated processing techniques designed to enhance present knowledge of processing small diameter seismic arrays for teleseismic event detection. Included in this research has been the design, fabrication, operation and evaluation of sophisticated on-line digital processing hardware for Wiener multichannel signal extration filtering, automatic event detection and classification processing.

This work has been conducted under the technical direction of the Air Force Technical Applications Center and was sponsored by the Advanced Research Projects Agency as part of the VELA UNIFORM program.

This annual report reviews the station operation, research and hardware development and evaluation conducted during the second contract year under AFTAC Project VT/6704 for the period May 1966 through April 1967. Work accomplished during the first contract year (AFTAC Project VT/5054) was documented in CPO Annual Report No. 1[1] and is reviewed and summarized in this report, where necessary, for continuity.

Sections in this report are organized as follows: Section II is summary and conclusions. Section III discusses station operation and analysis. Section IV presents results of the hardware evaluation and Section V summarizes the off-line applied research tasks. The appendix gives a complete list and brief description of all reports published under this contract.

SECTION II
SUMMARY AND CONCLUSIONS

During the past two years under Contract AF 33(657)-14648, a significant amount of information about on-line automated signal extraction and detection processing has been gained through the construction, operation and evaluation of the CPO MCF-Auxiliary Processor system. The following paragraphs summarize the use of the CPO MCF-Auxiliary Processor and related tasks and the significant results and conclusions reached.

A. STATION OPERATIONS

Operation of CPO continued routinely through the period May 1966 through April 1967. Collection of high-quality magnetic tape and film data was insured by an active quality control program and minimum station down time was guaranteed through a continuing preventive maintenance program.

Observatory primary, secondary, and long-period data were analyzed by the CPO analysis staff and reports of events were forwarded daily to the USC&GS. This data was also used for comparision in the MCF-Auxiliary Processor system evaluation.

At the close of this contract on 30 April 1967, the observatory and specified equipment, facilities and expendable supplies and parts were transferred to the USC&GS at the direction of the contracting officer. Disposition of other accountable property was accomplished prior to 30 April. The transfer went smoothly and according to schedule, and it was reported that the USC&GS personnel on-site were well satisfied with the transfer and conditions of facilities and equipment.

B. MCF-AUXILIARY PROCESSOR SYSTEM EVALUATION

The MCF-Auxiliary Processor system was designed, fabricated and evaluated under two task efforts. The MCF processor was built under VT/5054 and operated for a period of 6-½ months at CPO. Continued operation

of this program as well as the evaluation was conducted during the second year under VT/6704.

The Auxiliary Processor, which interfaces with the MCF, was designed and constructed during May 1966 through December 1966 and operated at CPO from 20 December 1966 through 10 April 1967.

Evaluation of these systems included a hardware reliability and maintenance study and a technical evaluation. (A brief description of the system has been provided in Section IV for reference.)

1. MCF Processor Evaluation

a. Hardware Reliability

The MCF proved to be a highly reliable digital processing device. For the first period the system operated on-line (15 March 1966 through 30 September 1966), a computed mean-time-between-failure of 900 hr was experienced after a 2000 hr "infant mortality" period. Not one component failure occurred from 20 December 1966 through 10 April 1967, approximately 2600 hr, which was the second period the system operated on-line at CPO. These results were considerably better than the theoretical mean-time-between-failure of 277 hr.

One design problem was experienced with the MCF system during the initial period it operated on-line at CPO. Wiener multichannel filter coefficients, which are stored in the processor memory, were lost or shuffled during routine operations. This difficulty, which was named the "coefficient loss problem", was caused by an internal grounding problem and an inability of the system to handle certain types of high speed power line transients. After the incorporation of suitable modifications, no serious difficulties with "coefficient losses" were encountered.

b. Technical Evaluation

The MCF processor output data were analyzed to determine the

impact on-line signal extraction processing and beam-steering had on the station detection capability. MCF output data were analyzed for teleseismic events and results of this analysis compared with routine CPO analysis using the primary and secondary data. These two sets of data were also compared with known seismic activity for two months' data (February and March 1967) to obtain a measure of the increase in detection capability provided by the MCF.

Results of the event detection study showed an average monthly increase of 58 percent for the 11 months the unit operated on-line. Using USC&GS data, it was demonstrated that examination of the MCF input data had aided the analysts in lowering perceptibility in secondary and primary data analysis by approximately 0.5 magnitude. Association of the two data sets for February and March 1967 with known seismic activity showed the MCF to detect 27 percent more events than the primary and secondary data in the prime detection range of $\Delta = 80^\circ - 90^\circ$.

Off-line investigation determined the amount of noise rejected by different filters for various types of noise. Filters used in the MCF had approximately the same degree of noise rejection on-line as they did in previous off-line analysis. The filters showed between 3.9 and 17.0 db improvement in the primary signal band of 0.6 to 1.4 cps for the samples analyzed and up to 18.6 db improvement above 1.4 cps. Further noise analysis compared the MCF outputs to sum and sum filtered data by computing microseism curves. Results of this study showed an average 2.4 to 7.3 db improvement using the MCF traces.

c. Conclusions and Recommendations

Based on the analysis of the processor operation during the two contract years, the following conclusions have been reached:

- The processor may be operated by a trained analyst
- The processor may be maintained by a trained technician

- Use of the processor indicates empirically a personnel decrease of one person required in the station analysis section as a result of the increased ease in detecting events
- At the CPO site no apparent need was evident which would warrant the updating of the MCF's, since consistent noise suppression was found during both contract years
- The processor increased the analyst's detection capability but the CPO station still did not report events from the northern hemisphere

From this study several recommendations based on results obtained from evaluating the data in Dallas and from analysts' evaluation of the processor are

- Primary on-line evaluation should be performed using the MCF data rather than secondary or primary data
- Use of the beam-steer capability in small arrays is useful even when resolution is limited. Also, some useful resolution is obtained for low-velocity signals from local or regional events
- The bandpass filter used at CPO had too narrow a passband and was limiting analysis, since it was rejecting a significant portion of some signals. A passband of 0.6 to 2.0 cps is recommended
- All beam-steer and MCF outputs should use frequency filters with the same passband

2. Auxiliary Processor Evaluation

a. Hardware Reliability

Evaluation of the processor hardware showed the system to be highly reliable. During the period of operation, 30 December 1966 to 10 April

1967, no component failures were reported. However, the initial setup and programing of the system is difficult and requires the empirical determination of many parameters. This is particuiarly true of the Fisher process, since knowledge of the Fisher intermediate terms must be known in order to determine the optimum data truncate settings.

b. Technical Evaluation

Evaluation of the Auxiliary Processor as a detection device indicated considerable difficulty exists in determining the fixed-threshold detection levels for the Fisher and Wiener outputs. Initial determinination of the desired threshold levels was difficult, and once the levels were determined, it was found that they were highly non-time stationary. Attempts to adopt standard procedures to update the threshold levels proved to be inadequate. Variations in the threshold level were significant enough that the automatic detection outputs were of little use to station analysts. An adaptation algorithm for use in the threshold detector is presented in CPO Special Report No. 5.[2]

The two UK outputs were programed in the Auxiliary processor, but were of limited use at CPO for classification for three reasons. First, UK processing is designed for use on large diameter crossarrays, but CPO is a small array and thus lacks sufficient resolution and violates the assumption that noise is uncorrelated across the array. Second, the two outputs may be programed for only two directions, severely limiting the class of signals which may be studied. Third, classification work requires preservation of signal waveform for all events. This causes a basic dynamic range conflict with the MCF which is a detection device requiring adequate noise for coherent noise suppression. The MCF-Auxiliary Processor system is limited to a 12-bit (66-db) dynamic range on input. Since on-line emphasis was placed on MCF signal extraction and detection processing, the class of signals available for study was highly restricted. Large signals of interest were clipped on input or during intermediate computations and small signals of interest were not detected on the

Develocorder display. Therefore, an adequate library of events for study was not collected.

Work in this area was subsequently shifted to the MCF and Auxiliary Processor evaluation. However, the identification processing technique warrants study if the processor is installed at a more suitable array location and sufficient events can be accumulated.

c. Conclusions and Recommendations

Much useful information for advancing the state-of-the-art of real-time automatic detection processing was gained by the implementation and evaluation of the CPO Auxiliary Processor. Both the Wiener power and the Fisher statistic computations appear to be useful for detection purposes, but completely automatic detection should use an adaptive threshold device. Such a device can easily be incorporated into the existing hardware with a relatively minor modification.

Little information was gained from computation of the UK technique on-line at CPO. The adverse array properties and dynamic range coupled with the sparsness of desired events severely limited the necessary library of events required for this study.

C. DALLAS RESEARCH

1. Ambient Noise

This study was directed toward determining the detailed configuration of the noise field at CPO, with emphasis placed upon the time stability of the noise. Knowledge of the noise structure as a function of time is necessary for optimum Wiener multichannel filter development, since the effectiveness of this type of processing depends upon the noise statistics used to synthesize the filters. If the ambient noise structure remains stationary in time and the statistics used in the filter synthesis adequately describe this structure, then the MCF will perform optimally over extended periods. However, if the ambi-

ent noise structure changes in time, the filter must be synthesized to include the statistics of the change.

The ambient noise field properties were analyzed during both contract years with regards to absolute power density spectra, spatially organized low-velocity noise, and spatially organized high-velocity noise.

Results of this study showed that the ambient noise field at CPO does not change significantly over extended time periods or on a daily or seasonal basis. However, a change in the noise field does exist which can be related to microseismic noise generated in the Atlantic and Gulf Coast regions, and possible the Great Lakes region.

These results imply that an accurate modeling of the CPO noise field can be used to generate a multichannel filter set which can be used in a DMCF processor to reject ambient noise throughout the year, except for periods of intense microseismic activity.

2. Detection Processing

Off-line Dallas-based support research was primarily directed toward determining parameters for the Auxiliary Processor program and toward investigating properties of the Fisher output. Two critical parameters, the integration gate length for the detection outputs and the low-cut frequency filter specification for the Fisher input data, were determined. Also the effect of correlated noise on the Fisher output was studied empirically in relation to the low-cut filter specifications. Compared to the Wiener outputs, signal attenuation for the Fisher computation as a function of wavenumber was determined to be significantly greater.

The variable threshold problem for a fixed false-alarm rate was investigated and found to be related to the RMS input noise level for the Fisher output. This increase could not be related to the effect of a particular noise contributor, but it may be related to the mantle P-wave noise level.

3. Visual Data Display

This task was directed toward improving visual Develocorder data displays in order to aid station analysts in interpretation of event arrivals. Two approaches to this task were analyzed, the development of single-channel filters to be applied on-line in the MCF to remove the system amplitude and velocity responses and a study of several variable display techniques.

In the single-channel filter study, it was found that extremely long filters would be necessary to successfully achieve the desired response and that these filters would require more core space in the MCF than is available. Therefore, this technique was discontinued. The other technique showed that variable area playbacks combined with band-pass filtering produce results which would be very advantageous in the analysis and reporting of small events. However, no method is currently available for on-line processing using this technique.

SECTION III

STATION OPERATIONS

A. DESCRIPTION

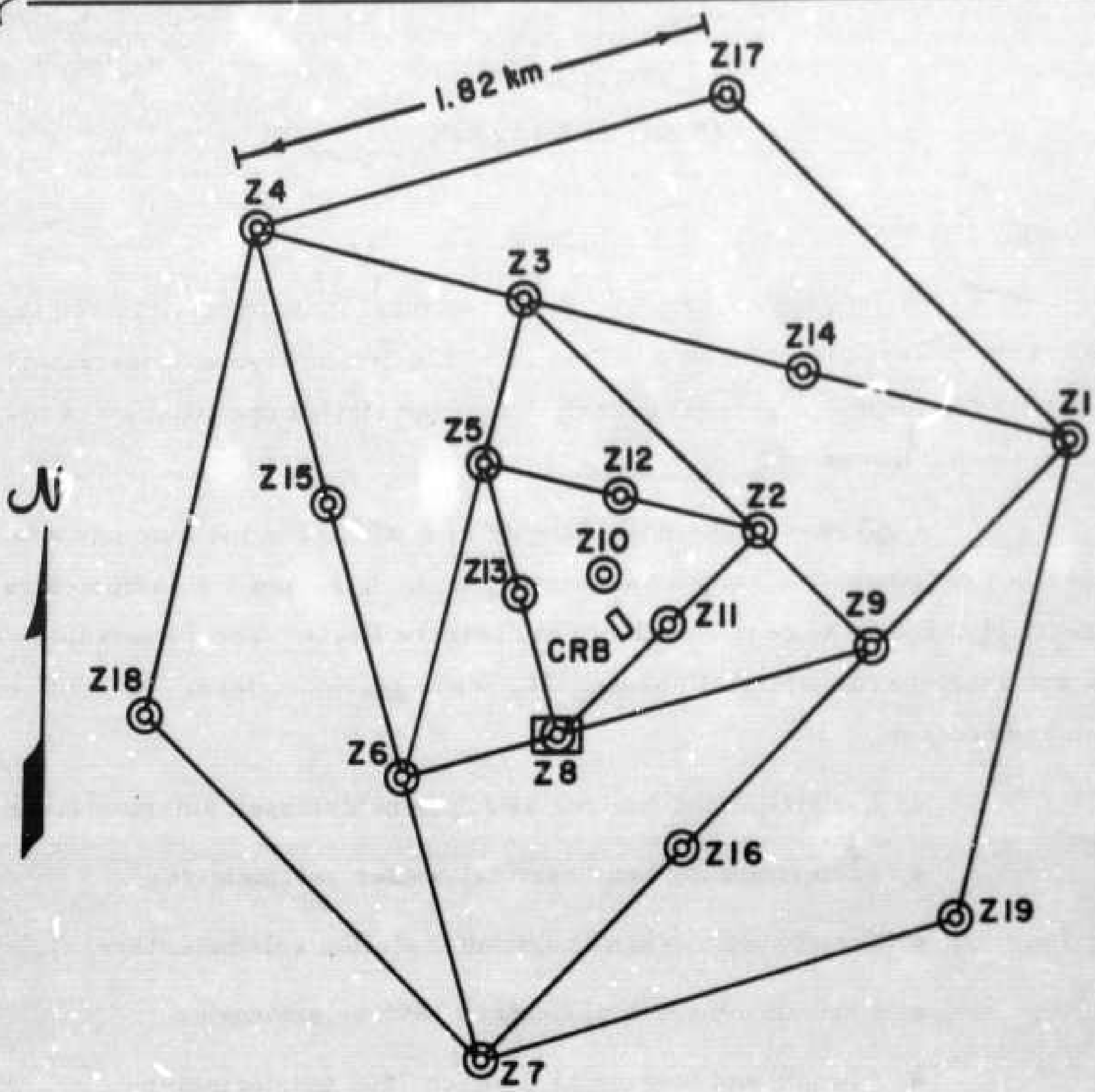
A detailed description of the technical instrumentation and facilities at the observatory can be obtained from the Seismological Observatories[3] information bulletin. A general description of the station operations and instrumentation follows.

CPO records seismic data 24 hr a day. The instruments are arranged in five concentric rings consisting of 1, 3, 3, 6, and 6 seismometers, respectively, from the center of the array (Figure III-1). The 19 seismometers are short-period vertical Johnson-Matheson seismometers. In addition, the array contains:

- 2 short-period horizontal Johnson-Matheson seismometers
- 1 intermediate-band vertical Melton seismometer
- 2 intermediate-band horizontal Melton seismometers
- 1 broadband vertical Geotech 7505 seismometer
- 2 broadband horizontal Geotech 7505 seismometers
- 1 long-period vertical Geotech 8700 A seismometer
- 2 long-period horizontal Geotech 8700 A seismometers
- 1 anemometer
- 1 earth-powered Benioff seismometer
- 2 high-frequency seismometers

The observatory also operates a digital multichannel filter processor (MCF) and a digital Auxiliary Processor.

For analysis and storage, all data are recorded on two 14-chan-



ARRAY CONFIGURATION CPO

SURVEY MARKER Z-8
LATITUDE - 35° 35' 41.42"N
LONGITUDE - 85° 34' 13.49"W
ELEVATION - 1883 FEET

ARRAY INSTRUMENT

TANK FARM

0 1/2 1 MILE

Figure III-1. CPO Array

nel tape recorders, two 16-channel Develocorders, one 20-channel Develocorder, and one 11-channel Develocorder. The latest channel designations for the various instruments are shown in Table III-1.

B. STATION ANALYSIS

1. Routine Analysis

Routine station analysis proceeded throughout the year. Station personnel analyzed all recorded events and, where possible, identified all recorded phases. Most common phases identified were P, pP, PP, PPP, PKP, S, SKS, SS, SSS, Lg, and Lr. Less common phases identified were PKKP, SKKS, PcP, ScS, and other core phases. Also, station personnel recorded T phases from one event.[4]

Other routine station analysis included the daily measurement of ambient-noise statistics used in the computation of AFTAC microseism curves and the daily telegramming of all recorded P-phase times to the USC&GS. These daily messages contained the arrival time of P and the period and amplitude of the maximum pulse.

Table III-2 presents the number of events reported by the station analysts during the year.

2. Special Projects

The special projects conducted at CPO during the last year included the continued compilation of an event library and analysis and evaluation of the MCF-Auxiliary Processor system. This latter task is discussed in detail in Section IV.

The event library consists of indexed reproductions (film and magnetic tape play back) of typical and interesting events as recorded at the observatory.

Table III-1

DATA FORMAT ASSIGNMENTS

CHANNEL NUMBER	DEVELOCORDERS				MAGNETIC-TAPE RECORDERS	
	Data Group 6000	Data Group 6036	Data Group 6025	Data Group 6035	Data Group 6017	Data Group 6034
	No. 1 & 2 SP Primary	No. 1 & 2 SP Secondary	No. 3 LP Primary	No. 4 MCF	No. 1	No. 2
1	V	V	W1	MCF 1 MCF 3-BP	TCDMG	TCDMC
2	Z7	ΣI	MS	MCF 2 IP 10-BP	Z1	LPZ
3	Z1	ΣK	ZLL	MCF 3 MCF 3	Z2	LPN
4	Z4	ΣL	NLL	MCF 4 MCF 24	Z3	LPE
5	Z2	ΣT	ELL	BSO Σ 19	Z4	UKO Russia
6	Z3	ΣTF	ZLP	BS 1 Σ 19 N	Z5	UK 1 NTS
7	Z5	ΣO	NLP	BS 2 Σ 19 E	Comp.	Comp.
8	Z6	ΣH	ELP	BS 3 Σ 19 S	Z6	Fisher
9	Z9	Z10	ML	BS 4 Σ 19 W	Z7	Z8L
10	ΣL	Z8L	Z8	ΣT	Z8	MCF 1 MCF 3-BP
11	ΣTF	Z8	WWV	MCFP 1	Z9	MCF 2 IP 10-BP
12	ΣT	NSP		MCFP 2	Z10	MCF 3 MCF 3
13	Z8L	ESP		MCFP 3	ΣTF	MCF 4 MCF 24
14	NSPL	UKO Russia		MCFP 4	WWV & Voice	WWV & Voice
15	ESPL	UK 1 NTS		Fisher		
16	WWV	WWV		Fisher Threshold		
17				MCFP 1 Threshold		
18				MCFP 2 Threshold		
19				MCFP 3 Threshold		
20				MCFP 4 Threshold		

Table III-2

NUMBER OF RECORDED EVENTS

Month	Teleseisms	Regional, Near-Regional and Local Events
May 1966	644	8
June 1966	699	3
July 1966	555	42
August 1966	599	8
September 1966	635	7
October 1966	601	10
November 1966	565	17
December 1966	567	2
January 1967	619	6
February 1967	630	10
March 1967	406	2
April 1967	342	10
Total	6862	125

An index card with information such as phase, arrival time, period, amplitude, and instruments that recorded the phase, distance, direction, location, and magnitude was prepared for each interesting event as determined by station analysts. The library was used by analysts to provide ready access to events for study and to aid in the identification of rarely seen phases.

C. ENGINEERING

1. Field Conditions

Existing CPO site field conditions make the repair and laying of cables a difficult task because the array is laid out through numerous swamps and bogs. These conditions make travel extremely difficult and require the use of four-wheel drive vehicles to traverse the trails to the vaults. The installa-

tion of AEI lighting protectors greatly reduces the amount of necessary field work.

2. Station Instrumentation

Throughout the past year station instruments have functioned well. However, some problems which occurred were

- Develocorder date timer malfunctions – the date timer in Develocorder No. 1 was replaced
- Beckman regulator and power control unit inoperative – replaced with new parts
- Leakage in calibration cable to Z-10
- Long-period Develocorder inoperative for several days
- Replacement of several DCM's

3. Quality Control

The CPO data were checked for quality control in several areas.

a. Develocorder Film Quality Control

1) Control Post Analysis Forms

The forms were checked for completeness and legibility to reduce errors in key-punching.

2) Daily Calibration Logs

The logs were checked for completeness, and comments were noted concerning problems encountered in operation.

3) Film Quality

The quality of film was compared with comments in calibration logs.

4) Data Quality

Data were checked by analysis of film for comparison with analysis forms. On this analysis,

- A check was made for missed events
- Phase identification was verified
- Measurement of events were made to check accuracy
- Calibration measurements were checked

Overall quality of the CPO film was good throughout the year, especially the latter part of the year Major problems were found in Develocorder stoppages and skipping. To alleviate this problem, a rotation system was set up which allow personnel to overhaul the Develocorders on a rotating schedule.

b. Magnetic Tape Quality Control

The following checks were performed on one tape per week, with all other tapes being spot checked.

1) Tape System Noise

- A visual inspection was made for dropouts and spikes
- Peak-to-peak wow and flutter measurements given in percent of deviation were made inside the seismic bandpass region
- A check was made for outside noise spikes such as Develocorder takeup, etc.
- Deterioration of data due to oxide buildup on heads was checked

2) Tape Alignment

- Center frequency and deviations were checked for alignment
- Average frequency readings were taken at three places to check for frequency drift of modulators
- Sine calibration was also checked for level, distortion and phasing

3) Seismometer Calibration

- Visual inspections were made of relative amplitudes and signal level
- Relative phasing was also checked

4) Time and Timing

- Voice quality, WWV quality and comments were checked
- Time code and WWV were checked for synchronization
- Tape start and calibration times were also checked

Overall quality of CPO magnetic tapes was good.

4. Modifications and Additions

Several modifications were introduced at the CPO station during the past year. The most significant change in the station operating configuration was the development of the Auxiliary Processor and the installation of the DMCF and Auxiliary Processors. An addition was the placing of the fourth Develocordor on-line to record all data produced by the digital processors.

SECTION IV
MCF — AUXILIARY PROCESSOR SYSTEM

A. MCF PROCESSOR

1. Description

The multichannel filter system uses digital processing techniques for simultaneous real-time filtering of several inputs through several filters. Since it is digital the system is highly reliable, can operate unattended over long periods of time, and any or all of its filter coefficients can easily be changed by programing the magnetic core memory from punched paper tape or from control panel switches. The processor has the capability of sampling 20 times/sec, processing up to five filters/channel, storing up to 512 points/filter, and beam-steering one of the five filters in up to 10 different directions. The system includes the following features:

- 32-channel input multiplier
- 12-bit analog-to-digital converter
- a multichannel filter digital processor
- an 8192-word by 24-bit ferrite core memory
- 14 digital-to-analog convertors for analog output
- a paper-tape reader for rapid loading of new filter routines
- a high-speed line printer for printing memory contents and self-test results

2. Operation

During the second contract year, the MCF processor was programed to operate using eight beam-steers and four MCF's. Filters and beam-steers used in the processor are shown in Table IV-1, and beam-steer

Table IV-1

PROCESSOR OPERATING MODE

Title	Description
BS0*	Straight sum (Z1 - Z19)
BS1	North, velocity = 12.6 km/sec (Z1 - Z19)
BS2	East, velocity = 12.6 km/sec (Z1 - Z19)
BS3	South, velocity = 12.6 km/sec (Z1 - Z19)
BS4	West, veloctiy = 12.6 km/sec (Z1 · Z19)
BS5**	In-line summation toward USSR using Z4, 6, 7, 9, 14, 15, 17, and 19
BS6**	Transverse summation toward USSR perpendicular to BS5
BS7**	In-line summation approximately toward NTS using Z1, 2, 8, 10, 11, 12, 13, and 18
BS8**	Transverse summation approximately toward NTS perpendicular to BS7
MCF0*	0.75 cps low-cut filter
MCF1	MCF3† convolved with 1.0- to 2.0-cps bandpass filter
MCF2	IP10WGS† convolved with 1.0- to 2.0-cps bandpass filter
MCF3	MCF3†
MCF4	MCF24†

* MCF0 subsection prefilters the 19-channel data and presents it for use in the BS subsection.

** Used as inputs to UK0 and UK1 of Auxiliary Processor.

† A complete description of the filters is discussed in Appendix A of CPO Annual Report No. 1.

delays corresponding to Table IV-1 are presented in Table IV-2.

The 1.0 to 2.0 cps bandpass filter used with MCF1 and MCF2 is shown in Figure IV-1. Also shown in Figure IV-1 is the 0.75 cps low-cut filter used in the MCF0 subsection of the processor. This particular filter is used because its output is processed through the Fisher section of the Auxiliary Processor, and results of testing different filters by the Fisher statistic have shown this to be the optimum filter for maximum rejection of coherent noise with minimum degradation of signals.[2]

3. Hardware Evaluation

a. Reliability

For the period 18 March 1966 to 30 September 1966 (when the processor was returned to Dallas for interfacing with the Auxiliary Processor), a mean-time-between-failures of 900 hr was computed.

For the period 19 May 1966 to 30 September 1966 (the period following "infant mortality" or 2000 hr when faulty components were identified and replaced and other maintenance problems normally found in new equipment were corrected), a mean-time-between-failures of 900 hr was computed. This 900-hr mean time was much better than that theoretically developed for the processor (277 hr).

On 20 December 1966, when the processor was returned on-line after interfacing with the Auxiliary Processor at the Dallas facility, no additional processor failures were encountered. This additional operation time from 20 December 1966 to 10 April 1967 indicates a significant increase in mean-time-between-failures. (The processor ran approximately 2600 hr without failure.)

b. MCF Coefficient Loss Problem

Since MCF processor installation at CPO in March 1966,

Table IV-2

CPO BEAM-STEER DELAYS*

Channel	BS0	BS1	BS2	BS3	BS4	BS5	BS6	BS7	BS8
Z 1	6	7	9	5	3	-	6	[illegible]	-
Z 2	6	6	7	6	5	-	6	5	-
Z 3	6	8	5	4	7	-	-	-	-
Z 4	6	8	4	4	8	9	-	-	7
Z 5	6	7	5	5	7	-	-	-	-
Z 6	6	5	5	7	7	5	-	-	7
Z 7	6	3	5	9	7	3	-	-	7
Z 8	6	5	6	7	6	-	5	7	-
Z 9	6	6	8	6	4	5	-	-	5
Z10	6	6	6	6	6	-	6	6	-
Z11	6	6	6	6	6	-	6	6	-
Z12	6	6	6	6	6	-	6	6	-
Z13	6	6	6	6	6	-	6	6	-
Z14	6	7	7	5	5	7	-	-	5
Z15	6	6	5	6	8	7	-	-	7
Z16	6	4	7	8	5	-	-	-	-
Z17	6	9	7	3	5	9	-	-	5
Z18	6	5	3	7	9	-	6	9	-
Z19	6	4	8	8	4	3	-	-	5

*All beam-steers have a 6-sample delay added to each channel. All delays are in terms of processor time frames, $\Delta t = 0.05$ sec/frame.

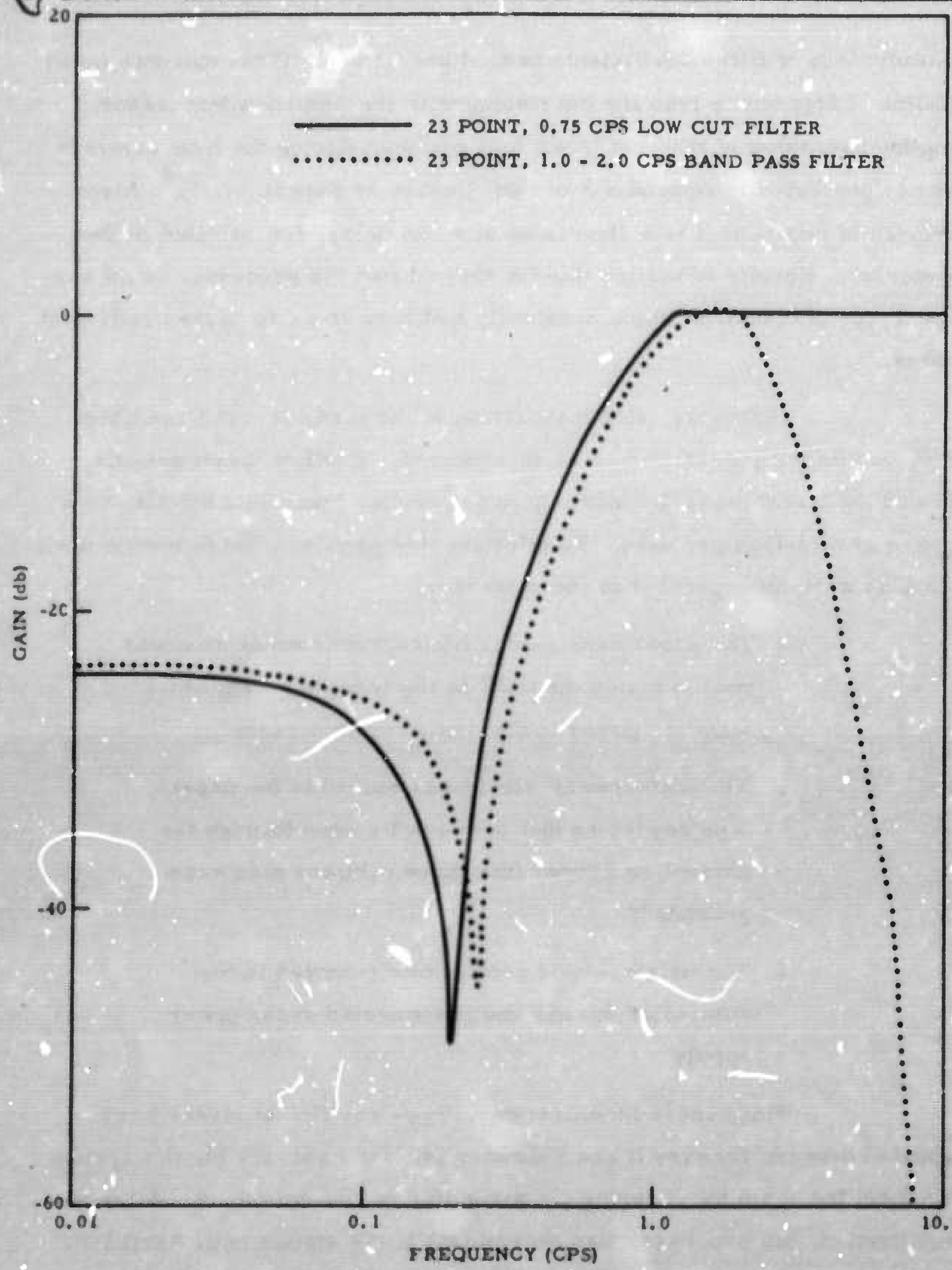


Figure IV-1. Responses of the 0.75-cps Low-Cut Filter and the 1.0-through 2.0-cps Bandpass Filter

sporadic loss of filter coefficients caused problems until the unit was taken off-line in September 1966 for interfacing with the Auxiliary Processor. A lengthy discussion of the coefficient loss problem during the first contract year is presented in Appendix A of CPO Quarterly Report No. 5.[5] Also included in this report is a discussion of a "no delay" fix installed in the processor. Results of testing this fix showed that the processor could survive a type of transient which previously had been found to cause coefficient losses.

However, after installation of the processor in December 1966, coefficient losses were still encountered. Further investigations showed the losses were due not only to power-line transients but also to a severe ground-loop problem. To alleviate this problem, the following modifications were incorporated in the processor.

- The paper-tape reader logic-ground connection was moved inside the MCF to the terminal strip which supplies power to the Auxiliary Processor
- The logic-power wiring was moved to the paper-tape reader so that it was not routed through the controller drawer (the three cabinets also were grounded)
- The printer-logic ground was removed to the controller drawer and reconnected at the power supply

Since these modifications, three coefficient losses were reported between January 11 and February 14. On February 14, the system was modified again by changing the grounding on the time input. After this modification, the processor was operational at the station until April 1967 with only one coefficient loss occurring on March 7 during a severe electrical

storm. Therefore, it can be concluded that the additional modifications made have essentially eliminated the coefficient-loss problem.

4. Technical Evaluation

a. Event Detection

To examine the increase in detection capability afforded the CPO analysts by the MCF processor, a study was performed to determine how many additional events the analysts could detect using the MCF data than they could without using the MCF data. In this study, analysts compiled two separate events lists. One of these lists was compiled using only the MCF data and the other list was compiled using the primary and secondary data excluding the MCF traces. Results of their study are summarized in Table IV-3.

Table IV-3 demonstrates that the MCF addition to the observatory significantly increased the number of events reported. Through September 1966, there was an average monthly increase in events picked of 70 percent compared with the station average from May 1965 through September 1966.

Further demonstration of the increased detection caused by the installation of the MCF is shown in Figure IV-2, which shows the perceptibility curves for CPO data for four different time periods: before use of the MCF, 1963; June and July 1965; January, February and 1/2 of March 1966; and after the use of the MCF, February and March 1967. This figure shows that average perceptibility was lowered by as much as 0.2 magnitude from the spring of 1965 when the analysts went to CPO to March 1966 when the processor was installed. Perceptibility was lowered by as much as 0.5 magnitude from the 1963, 1965, and 1966 data to the 1967 data after the processor installation. It is apparent from this that the processor has produced a "learning effect" at CPO which caused the large increase in primary

Table IV-3

COMPARISON OF EVENT DETECTION

Date	Primary and Secondary	MCF	Comments
May 1965	281		
June 1965	375		
July 1965	318		
Aug 1965	319		
Sept 1965	250		
Oct 1965	308		
Nov 1965	315		
Dec 1965	291		
Jan 1966	272		
Feb 1966	329		
Mar 1966	---	399	MCF installed 8 March
Apr 1966	---	461	
May 1966	---	644	
June 1966	---	649	
July 1966	306*	555(501)*	Primary and secondary data analyzed in Dallas
Aug 1966	358*	549(523)*	
Sept 1966	359*	635(550)*	MCF removed on 30 Sept
Oct 1966	601		
Nov 1966	565		
Dec 1966	567		MCF installed 30 Dec
Jan 1967	619	1367	MCF event count inaccurate because of threshold problem
Feb 1967	630	679	
Mar 1967	406	611	10 Mar analyst personnel change
Apr 1967	342 (128)*	274*	MCF removed on 10 April. Station close-out conducted during April

* Adjusted for days MCF off-line

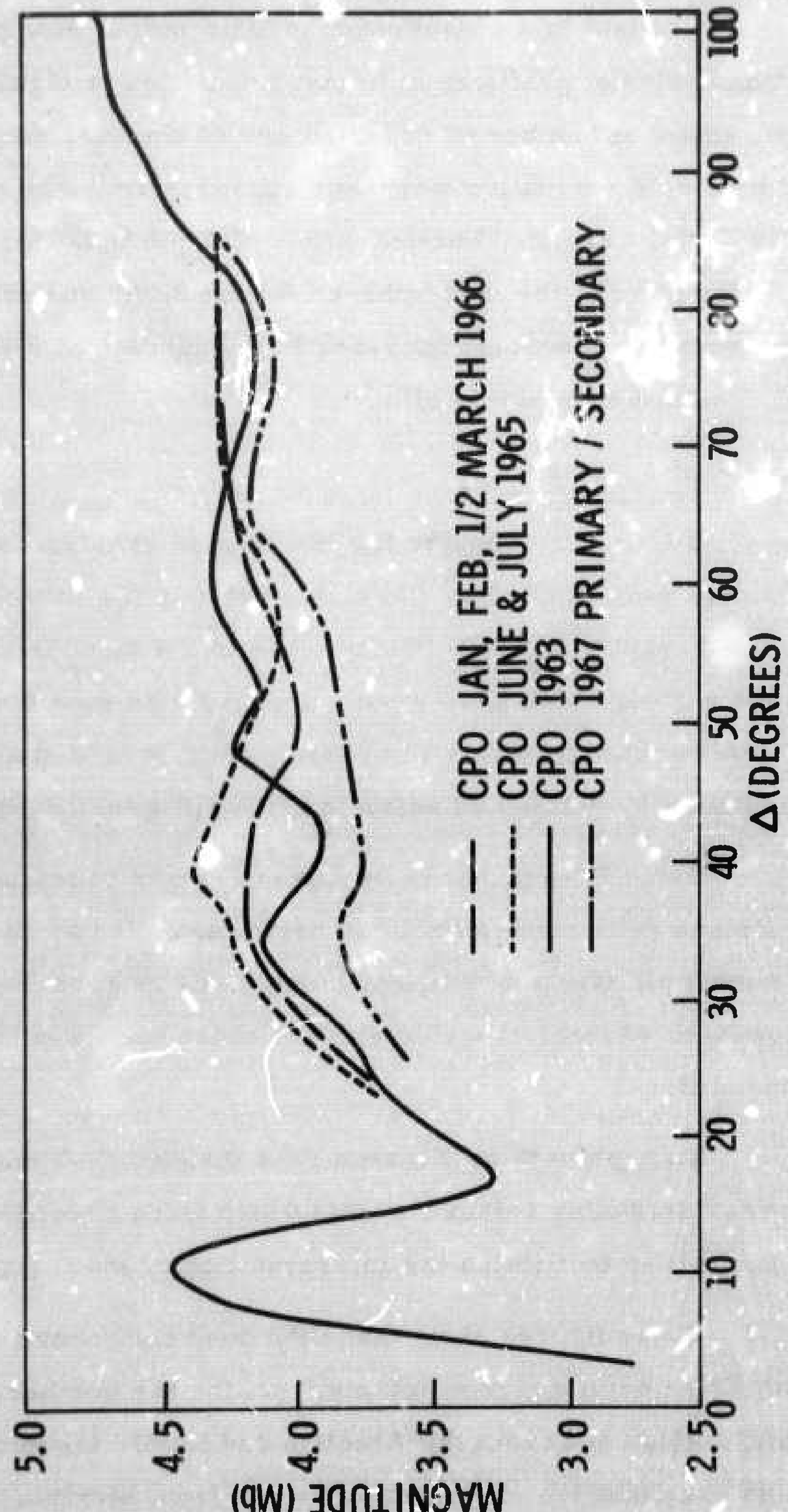


Figure IV-2. CPO Perceptibility Curves

and secondary reported events, as shown in the table.

The fact that examination of MCF output data had an impact on the station analysts' proficiency in event detection is significant. The MCF improvement in number of reported events obtained during the last four months of MCF evaluation work was subsequently reduced considerably. February 1967, for example, showed only a 7.8 percent increase. However, as will be pointed out in the next subsection, the MCF was still able to demonstrate as much as 27 percent increase in the number of reported and associated results as a function of Δ.

b. Event Association

To further compare the two lists of events, February and March 1967 data were studied to determine not only the increase in the number of reported events, but also the increase in the number of associated events. In this study, both lists were compared with known seismic events, and results were obtained which compared events recorded and with respect magnitude, azimuth, delta, and seismic region (Figure IV-3).

Table IV-4 presents number of events reported and missed vs magnitude and delta ranges (in 10° increments). It can be seen from this table that nearly all events of magnitude ≥ 4.3 will be recorded in the 20°-90° range. However, several areas do exist in which the majority of the events are not recorded.

To explain this, Figures IV-4 through IV-7 were plotted to show the areas producing seismic events which were recorded and missed at CPO. Table IV-5 facilitates the interpretation of these figures.

These figures show that CPO does not record many events from the northern hemisphere — notably from the far northern part of the North Atlantic Ridge and from the Aleutian and Kurile Islands. However, CPO does an excellent job of recording events from Mexico, Central America,

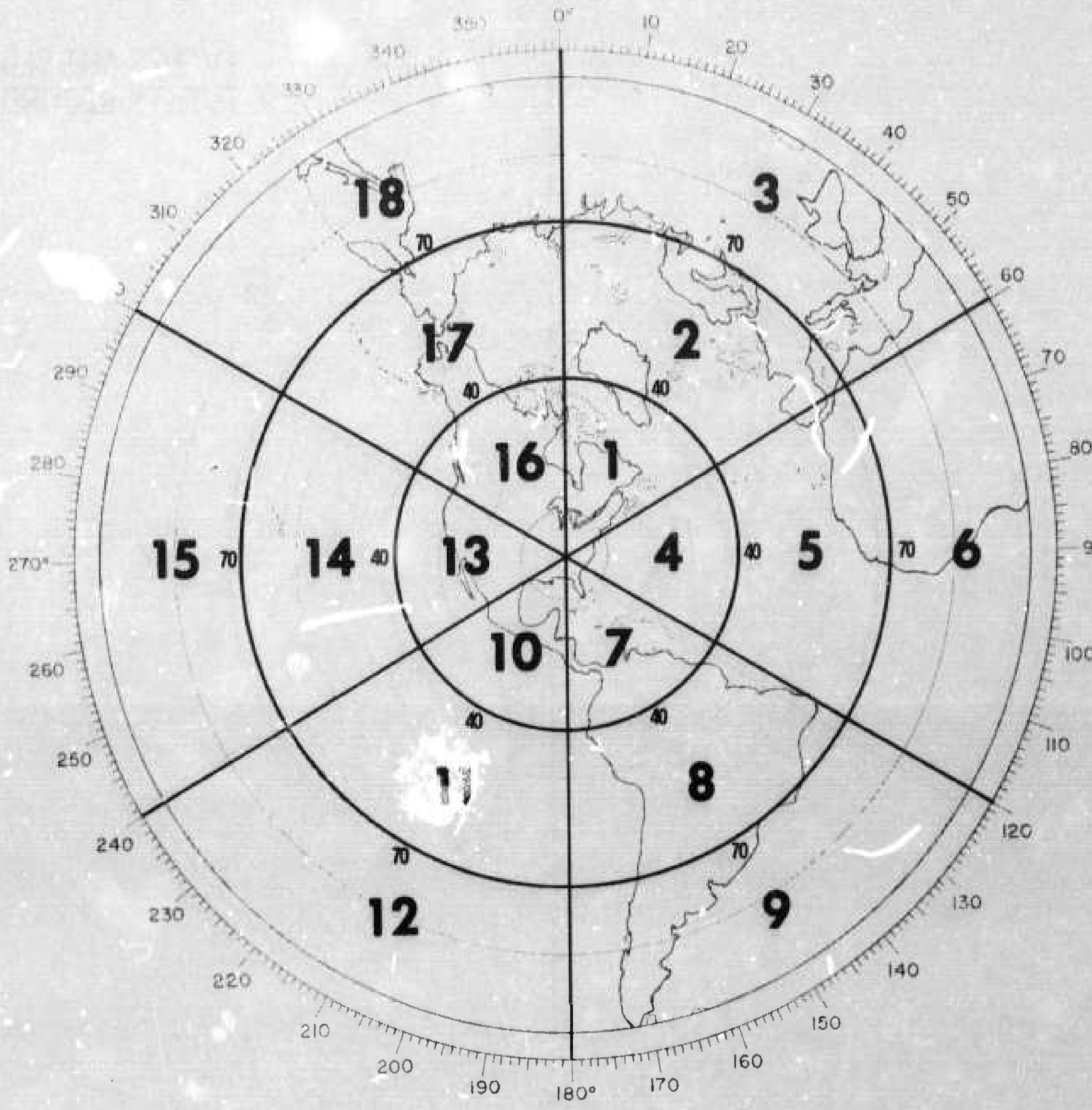
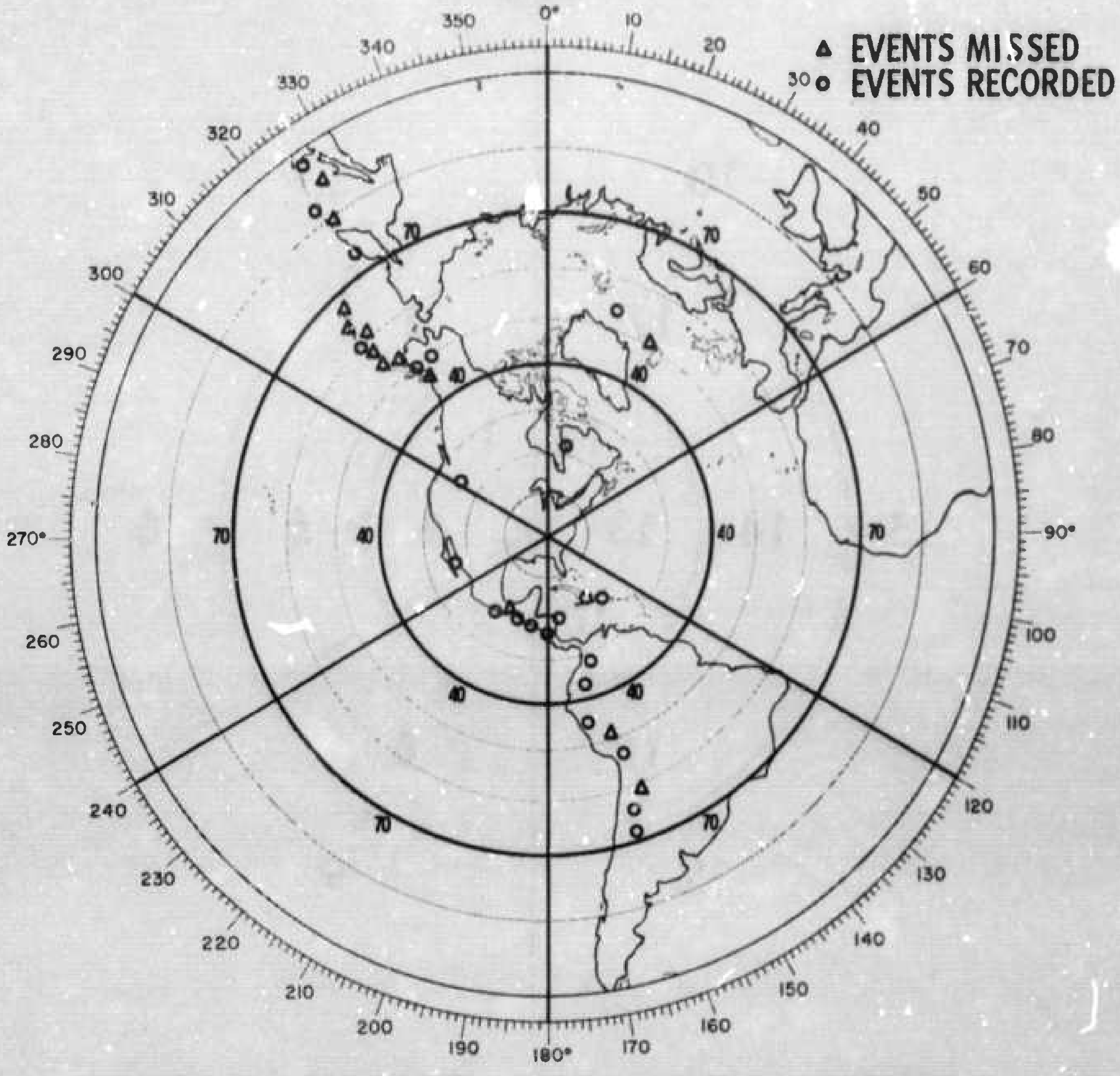


Figure IV-3. Seismic Regions

CPO FEB & MARCH 1967
M≤3.7



EACH POINT REPRESENTS APPROXIMATELY FOUR EVENTS

Figure IV-4. CPO Event Detection, M ≤3.7

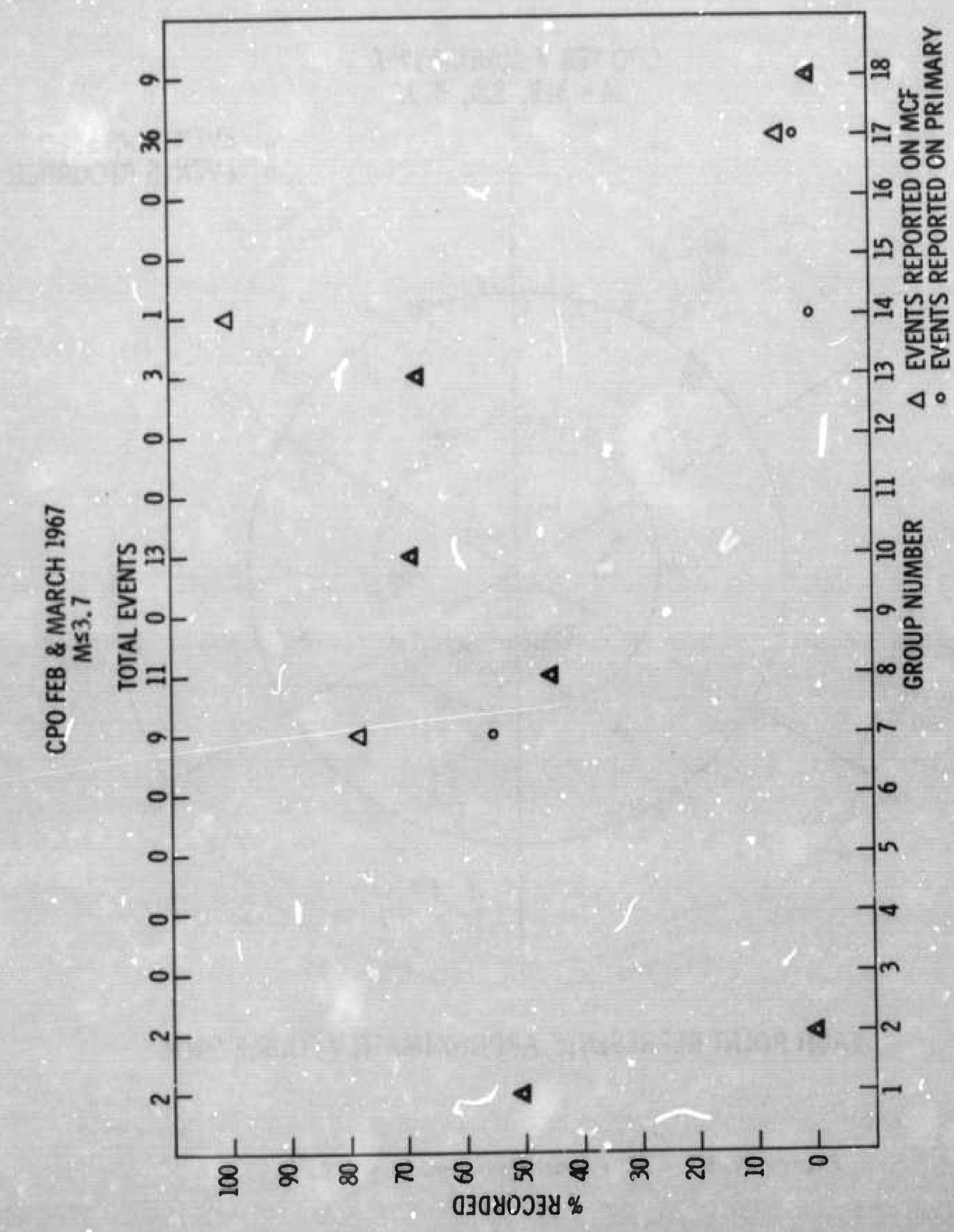


Figure IV-4. (Continued)

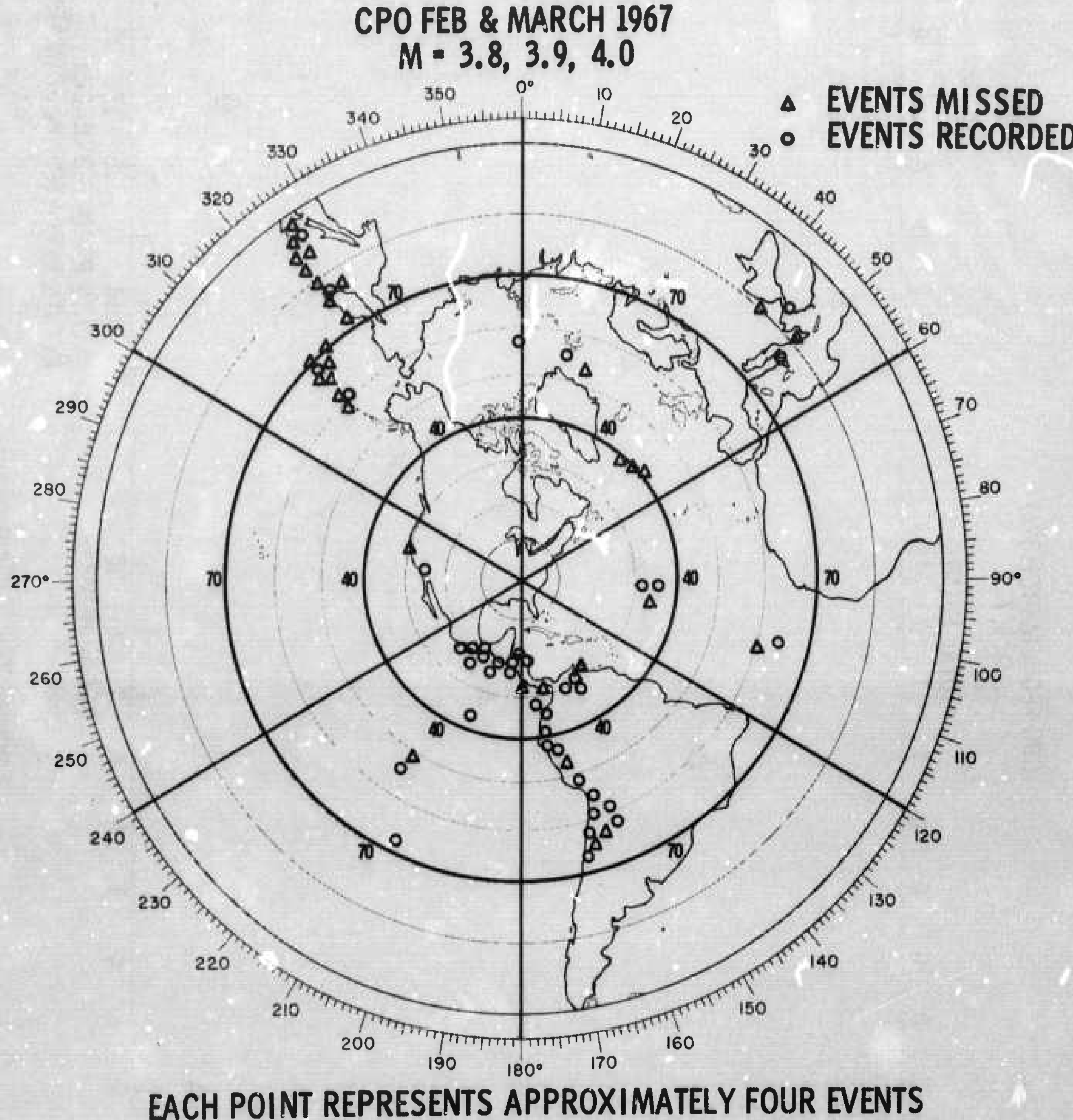


Figure IV-5. CPO Event Detection, M = 3.8, 3.9, 4.0

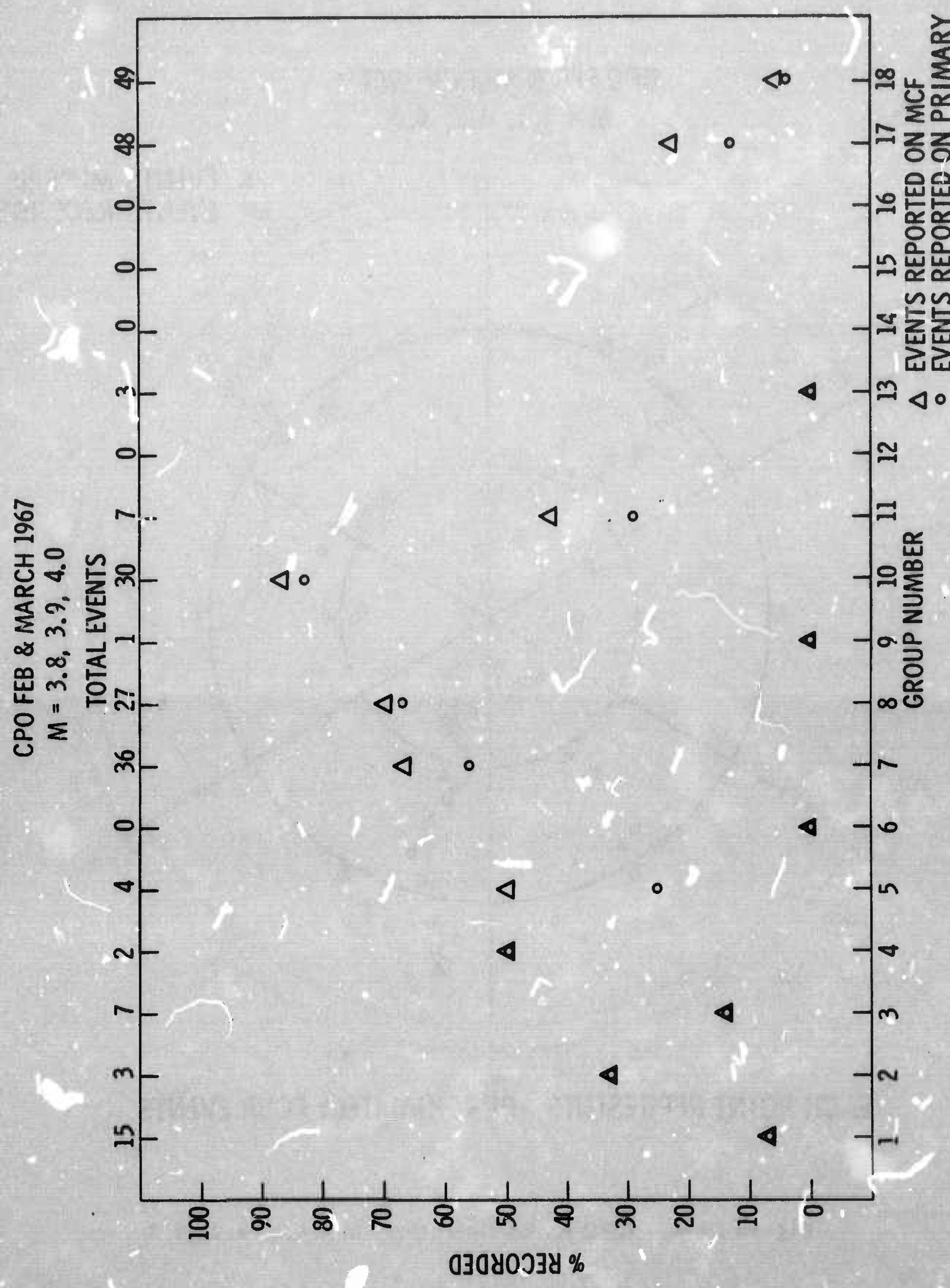


Figure IV-5. (Continued)

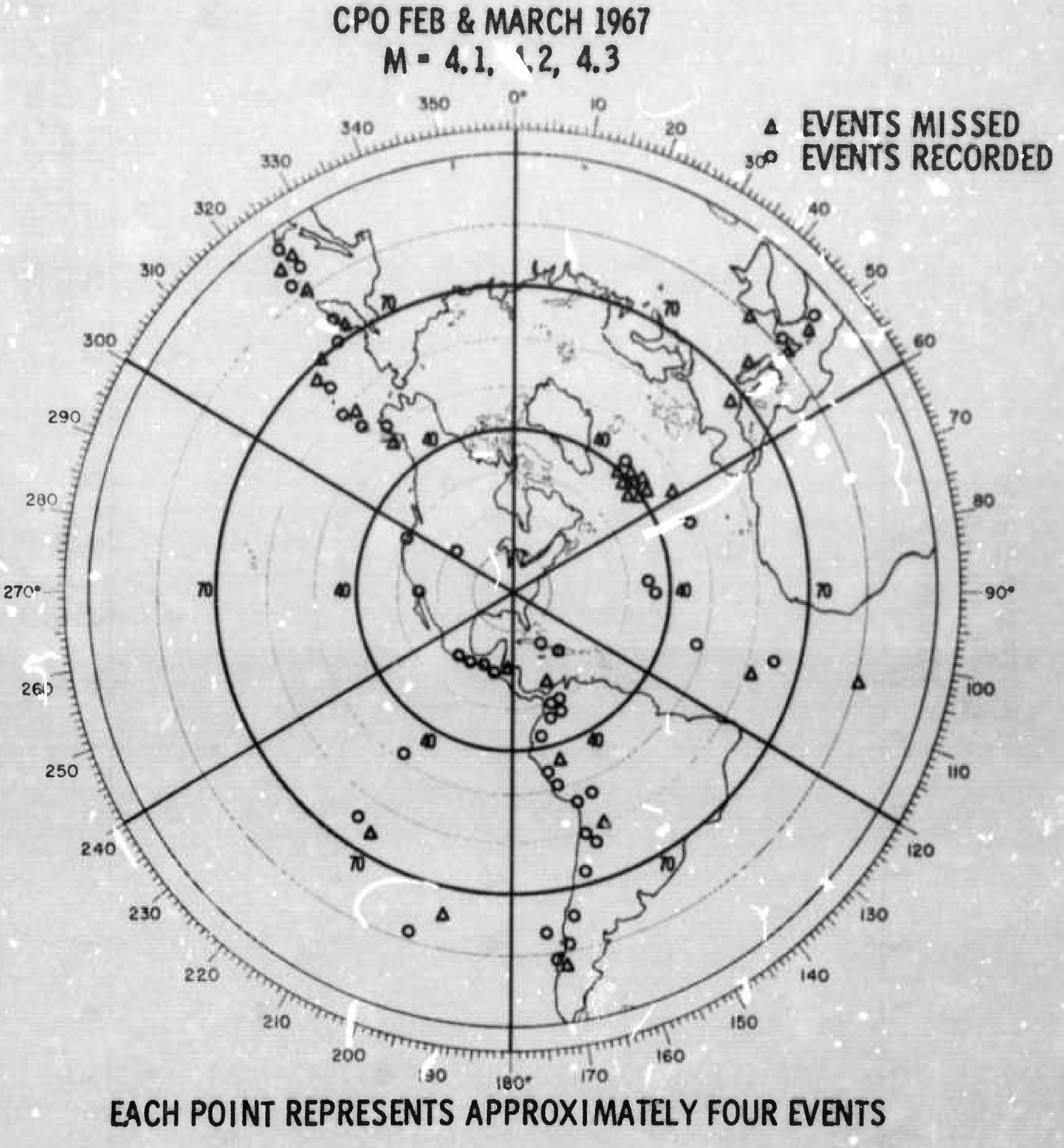


Figure IV-6. CPO Event Detection, M = 4.1, 4.2, 4.3

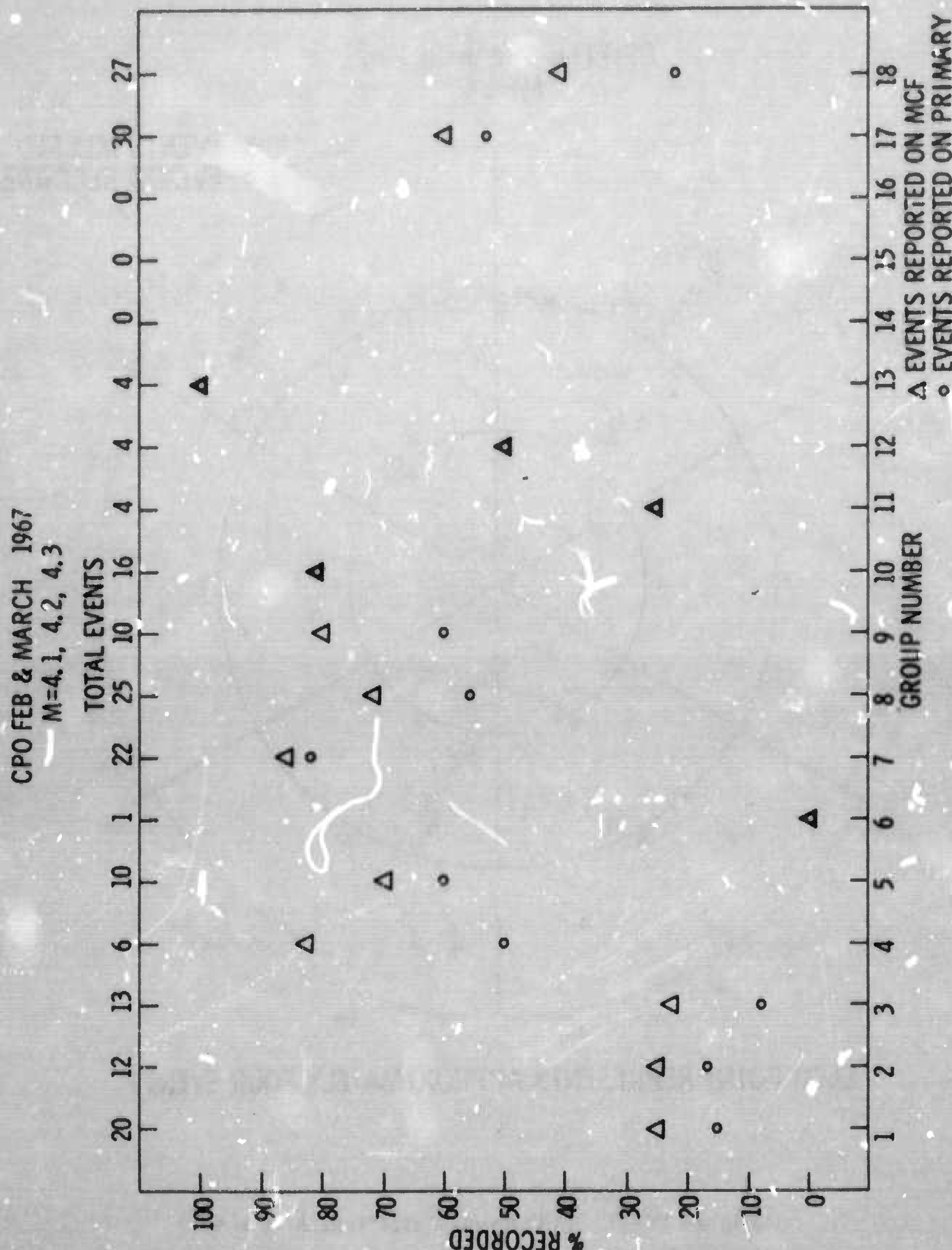


Figure IV-6. (Continued)

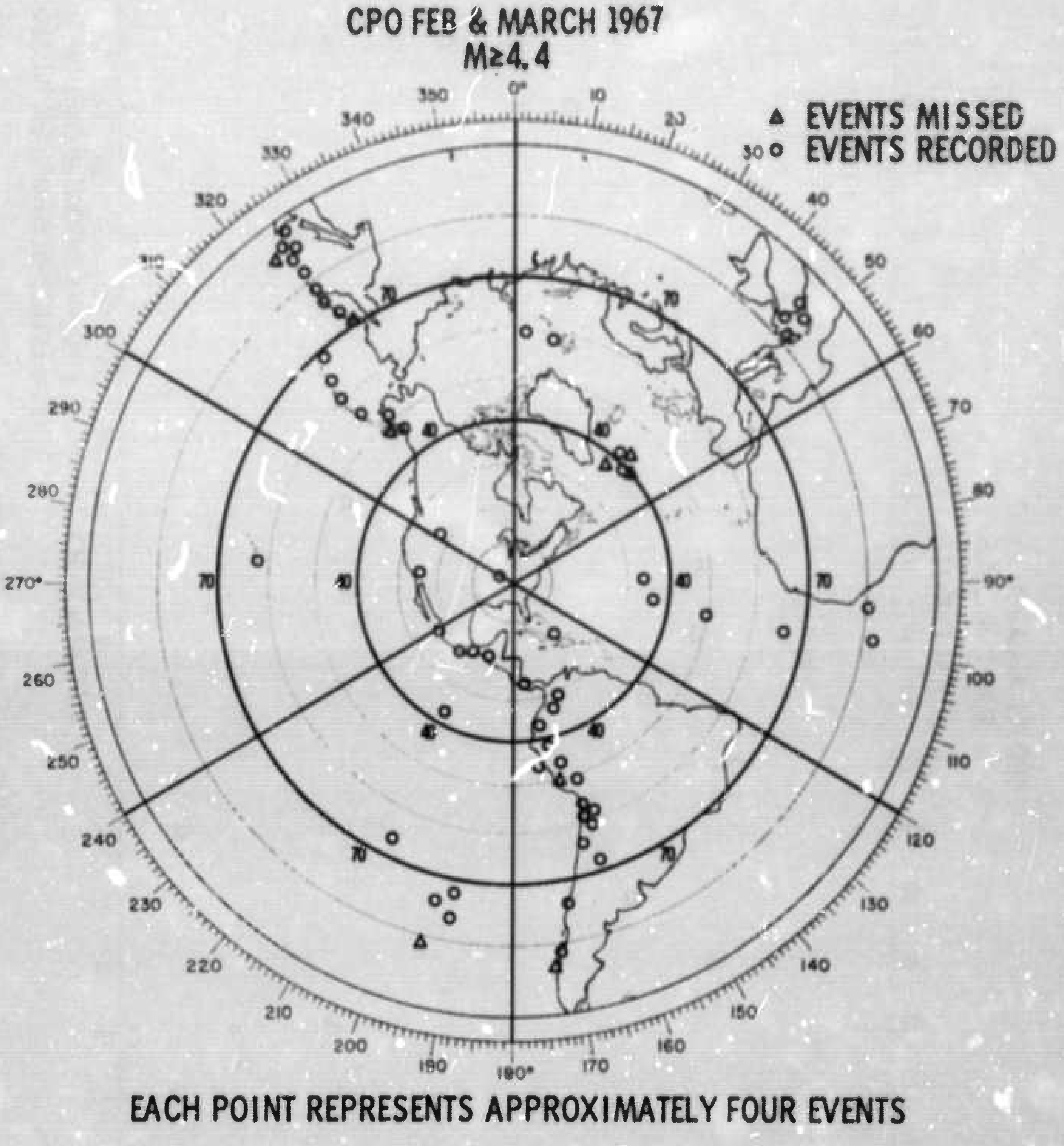


Figure IV-7. CPO Event Detection, M ≥ 4.4

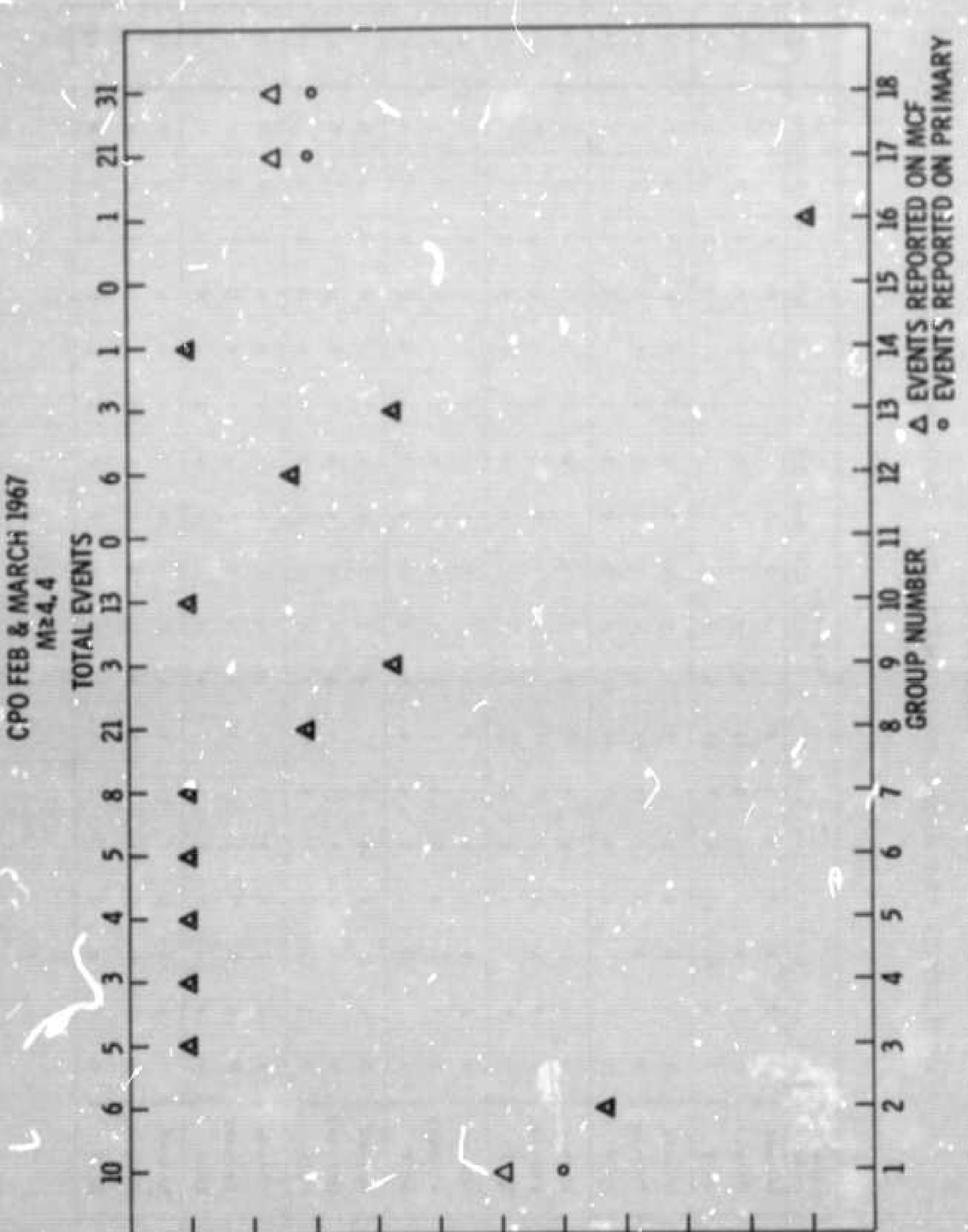


Figure IV-7. (Continued)

Table IV-4

CPO FEBRUARY AND MARCH 1967 EVENT ASSOCIATION RESULTS

Delta	Associations	Magnitude <3.6	3.6	3.7	3.8	3.9	4.0	4.1	4.2	4.3	4.4	4.5	4.6	4.7	4.8	4.9	5.0	>5.0	No Mag	Total
20°-30°	Missed	0	2	2	3	3	3	2	2	0	0	1	0	0	0	0	0	0	1	19
	Primary	5	1	9	7	10	8	13	6	0	7	1	4	3	1	0	0	0	5	80
	MCF	5	2	10	11	10	9	13	6	0	7	1	4	3	1	0	0	0	5	87
30°-40°	Missed	1	0	2	4	5	6	4	5	9	1	3	2	0	0	0	0	0	8	50
	Primary	0	1	2	2	9	10	10	8	2	3	0	4	1	1	1	0	4	3	61
	MCF	0	1	2	2	9	10	11	11	4	3	0	5	1	1	1	0	4	3	68
40°-50°	Missed	0	4	4	3	4	5	7	2	3	6	0	0	0	1	0	0	0	9	48
	Primary	0	0	1	4	3	2	5	1	3	3	0	2	2	1	0	2	1	0	30
	MCF	1	0	1	4	3	2	6	2	3	3	0	2	2	1	0	2	1	0	33
50°-60°	Missed	8	6	3	11	3	3	3	0	1	0	0	0	1	0	0	0	1	2	42
	Primary	2	1	0	0	6	4	4	7	3	2	1	3	2	0	2	0	3	1	41
	MCF	2	1	0	1	9	4	4	8	4	2	1	3	2	0	2	0	3	1	47
60°-70°	Missed	2	8	7	1	14	9	10	4	1	1	1	1	0	0	0	0	0	0	59
	Primary	0	1	1	2	5	3	6	8	4	6	4	3	2	0	0	1	1	0	47
	MCF	0	1	2	2	7	5	8	9	4	6	5	3	2	0	0	1	1	0	56
70°-80°	Missed	1	1	2	8	7	6	5	4	6	0	0	1	0	0	0	0	0	0	41
	Primary	0	0	0	0	1	1	3	3	1	1	2	4	3	4	0	1	3	1	28
	MCF	0	0	0	0	1	1	5	4	2	2	2	3	3	4	0	1	3	1	33
80°-90°	Missed	1	2	3	6	12	13	9	5	2	1	0	1	1	0	0	0	2	0	58
	Primary	0	0	0	0	0	0	0	2	4	3	3	2	5	2	0	0	5	0	26
	MCF	0	0	0	0	0	1	1	2	8	3	3	3	5	2	6	0	5	0	33

Table IV-5

CPO MAJOR EVENT PATTERNS OF RECORDING FOR FEBRUARY AND MARCH 1967

Magnitude	Area	Pattern of Event Recording
$M \leq 3.7$ (Figure IV-4)	7	Majority recorded
	8	Gray area at 50°
	10	Majority recorded
	17	Missed
	18	Missed
$M = 3.8, 3.9, 4.0$ (Figure IV-5)	1	Missed
	3	Missed
	7	2/3 recorded
	8	Gray area at 63°
	10	Majority recorded
	17	1/4 recorded
	18	Missed
$M = 4.1, 4.2, 4.3$ (Figure IV-6)	1	Missed
	2	Missed
	3	1/4 recorded
	7	Majority recorded
	8	2/3 recorded (majority of the events at 45° to 55° and inland from coast are missed)
	10	Majority recorded
	17	1/2 recorded
	13	1/3 recorded
$M \geq 4.4$ (Figure IV-7)		Nearly all events in this magnitude range are recorded excluding nine from areas 1 and 2 and several from groups 8 and 18

and the northern part of South America, with the exception of a few gray areas in South America.

Examination of Table IV-4 shows that the MCF list associated 44 events not on the primary list. No relationship could be found between the 44 associated events and their magnitude, distance or location.

An analysis of the event association data in Table IV-4 on the basis of Δ indicates a 27 percent increase in events detected by the MCF for the prime detection range of 80° to 90° (Table IV-6). The percent improvement drops to 9 percent for $\Delta = 20°$ to 30°, as would be expected on the basis of the MCF wavenumber response.

A comparison between the MCF improvement and the MCF wavenumber ($\vec{k}$) response is shown in Figure IV-8. The $\vec{k}$ response represents the average isotropic response for MCF3, MCF24 and IP10 WGS (filters applied on line during this period) at 1.0 cps. Data upon which this response is based was presented in Appendix A of CPO Annual Report No. 1.[1]

Figure IV-3 demonstrates reasonable agreement between the MCF improvement for associated events and the $\vec{k}$ response of the MCF coefficients.

Since perceptibility at CPO had been lowered by as much as 0.5 magnitude for primary and secondary event reporting as a result of the MCF operation at CPO, it is significant that measurable improvement is still demonstrated during the February and March 1967 MCF evaluation period.

Table IV-6

MCF ASSOCIATED EVENT IMPROVEMENT

Δ (°)	Percent Improvement	db Improvement
20-30	7	0 74
30-40	11	0.94
40-50	10	0.84
50-60	15	1.18
60-70	19	1.52
70-80	18	1.40
80-90	27	2.08

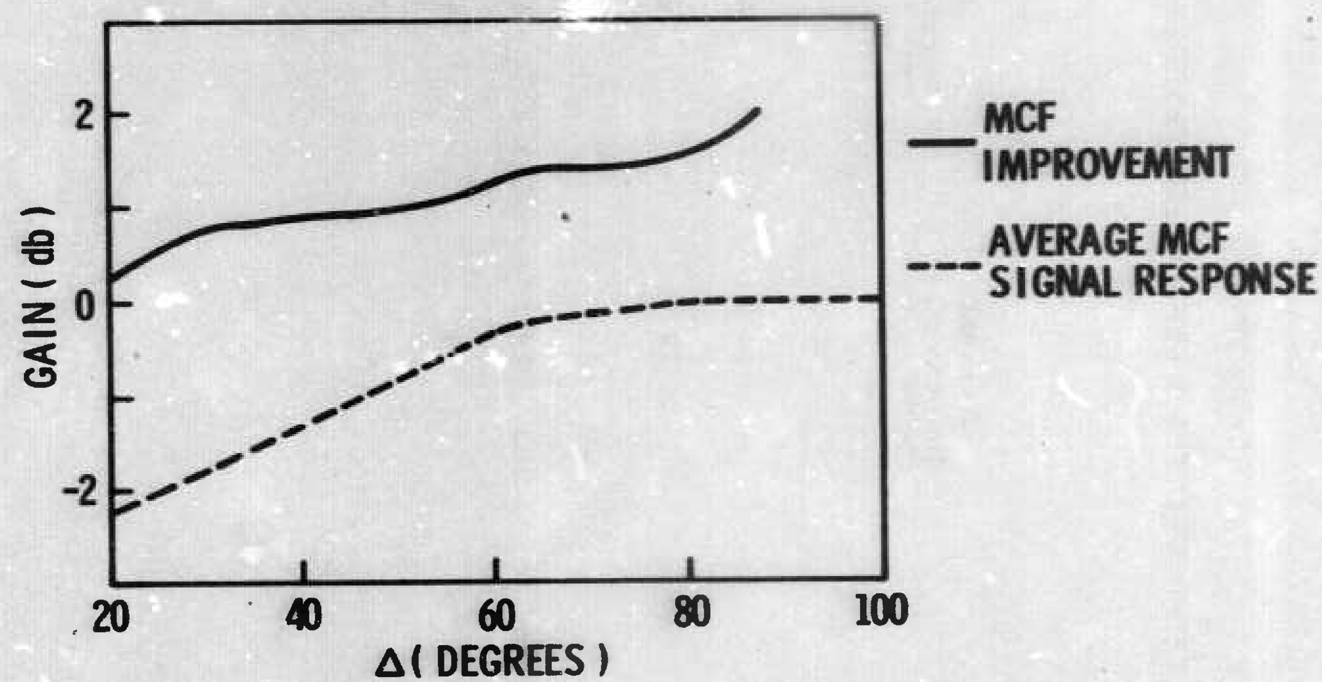


Figure IV-8. Comparison of MCF Event Association Improvement and MCF $\vec{k}$ Response

c. Noise Study

To study the amount of noise rejection achieved by the MCF, the following three noise samples were digitized and noise rejection curves were plotted.

- Day 033 - quiet sample
- Day 046 - normal sample
- Day 046 - noisy sample

These three samples were chosen as representative of the majority of the noise conditions at CPO, thus producing a good representation of how the processor would react under most conditions encountered.

To compare the MCF's with each other and with previous off-line analysis, the responses were corrected as follows:

- Correct all traces to absolute power relative to 1.0 $m\mu^2$/cps at 1.0 cps with Z-5 as reference by performing calibration analysis on each trace
- Remove the effect of the processor (Figure IV-9) from each trace
- Remove the effect of the 1.0- through 2.0-cps passband filter (Figure IV-1) convolved with MCF1 and MCF2

After removing these three factors from the MCF outputs and correcting trace Z-5 to absolute power, N_o/N_i curves were computed and are shown in Figures IV-10, IV-11 and IV-12 for the quiet, normal and noisy samples, respectively. Noise improvement shown in these illustrations is summarized in Table IV-7.

Comparison of the data in Figures IV-10 through IV-12 with previous off-line analysis indicates that, in general, the processor is

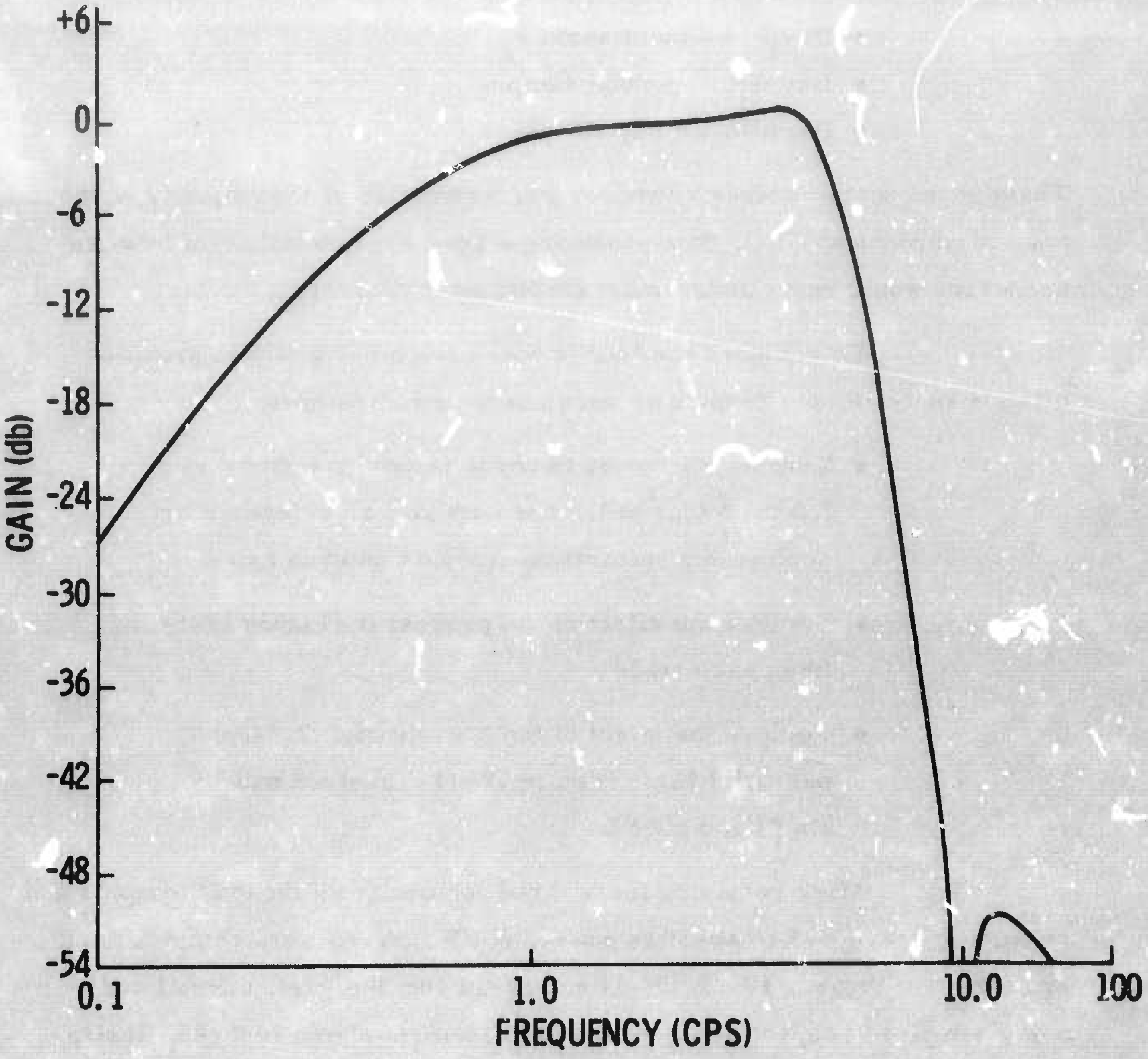


Figure IV-9. Typical Amplitude-Response Signal-Conditioner Channels

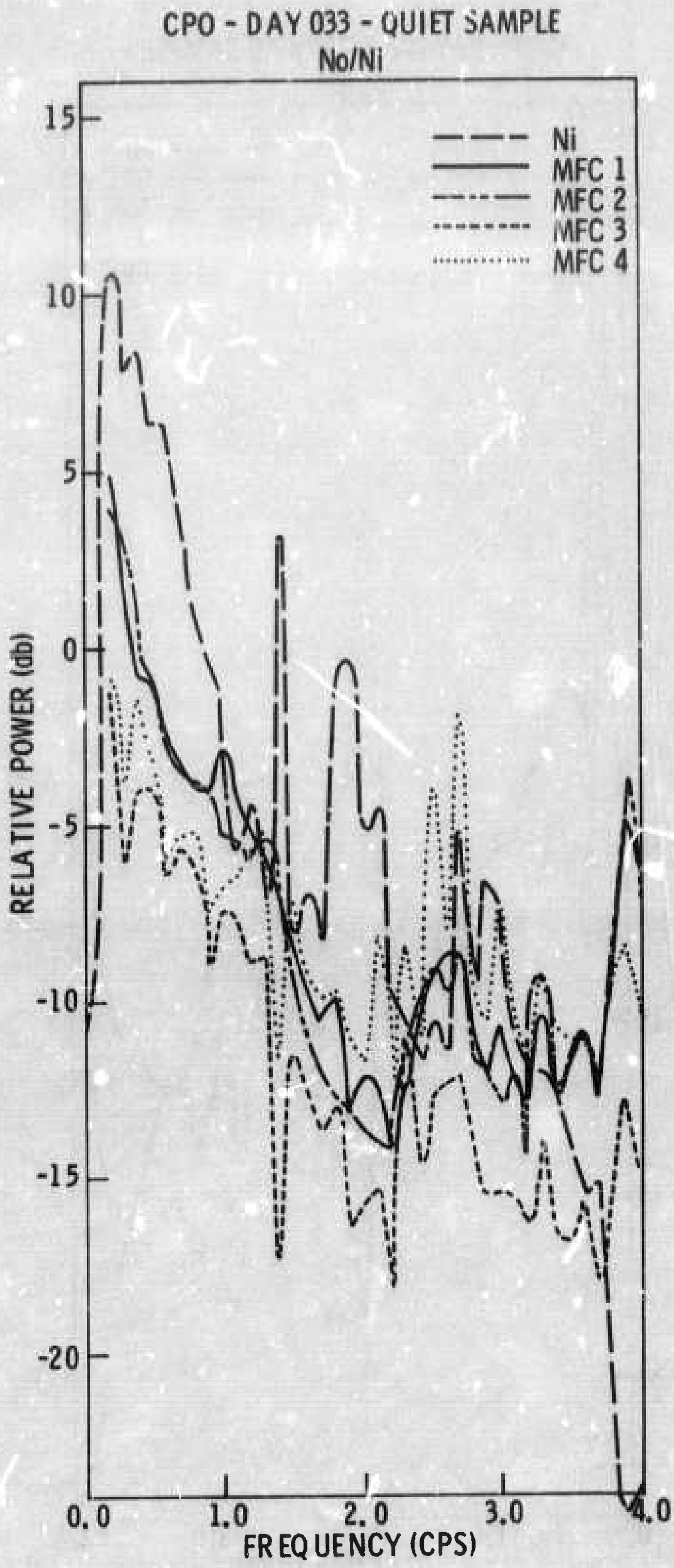


Figure IV-10. N_o/N_i Curves for Day 033 - Quiet Sample

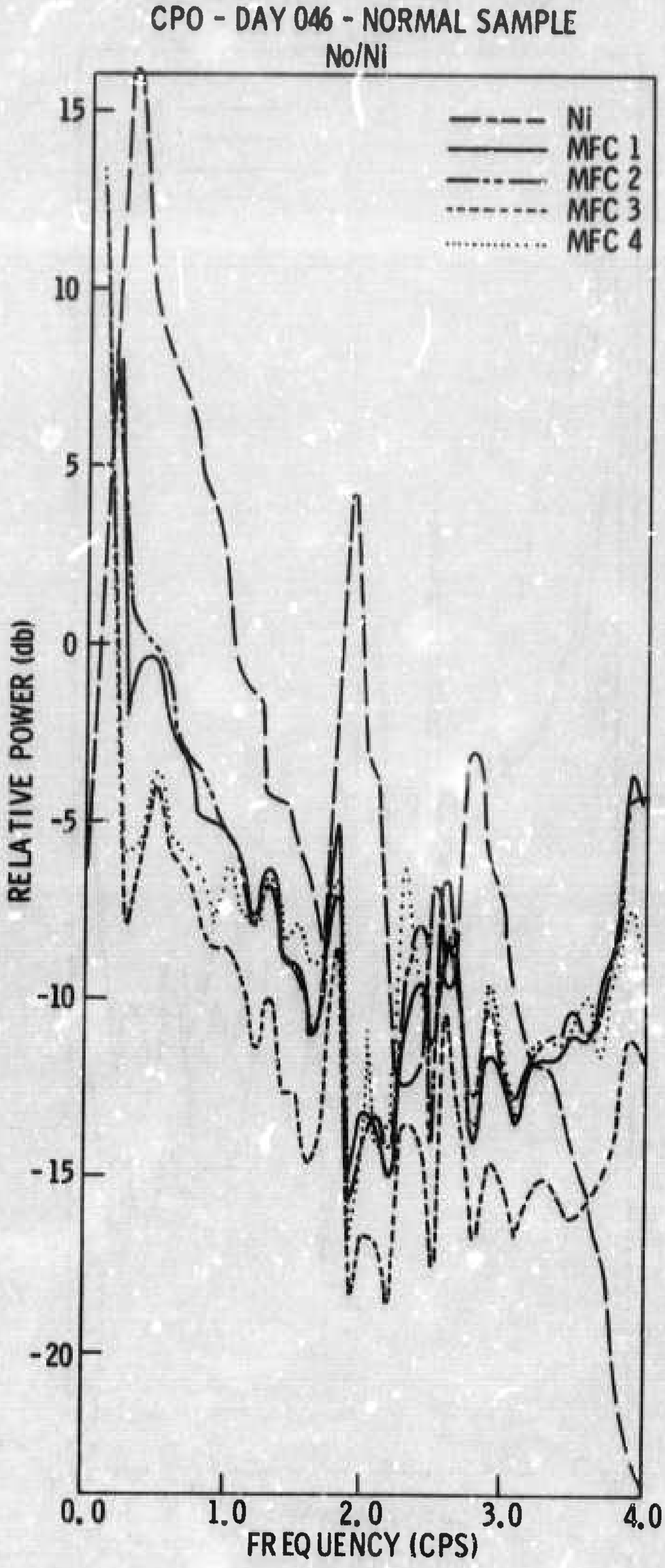


Figure IV-11. N_o/N_i Curves for Day 046 - Normal Sample

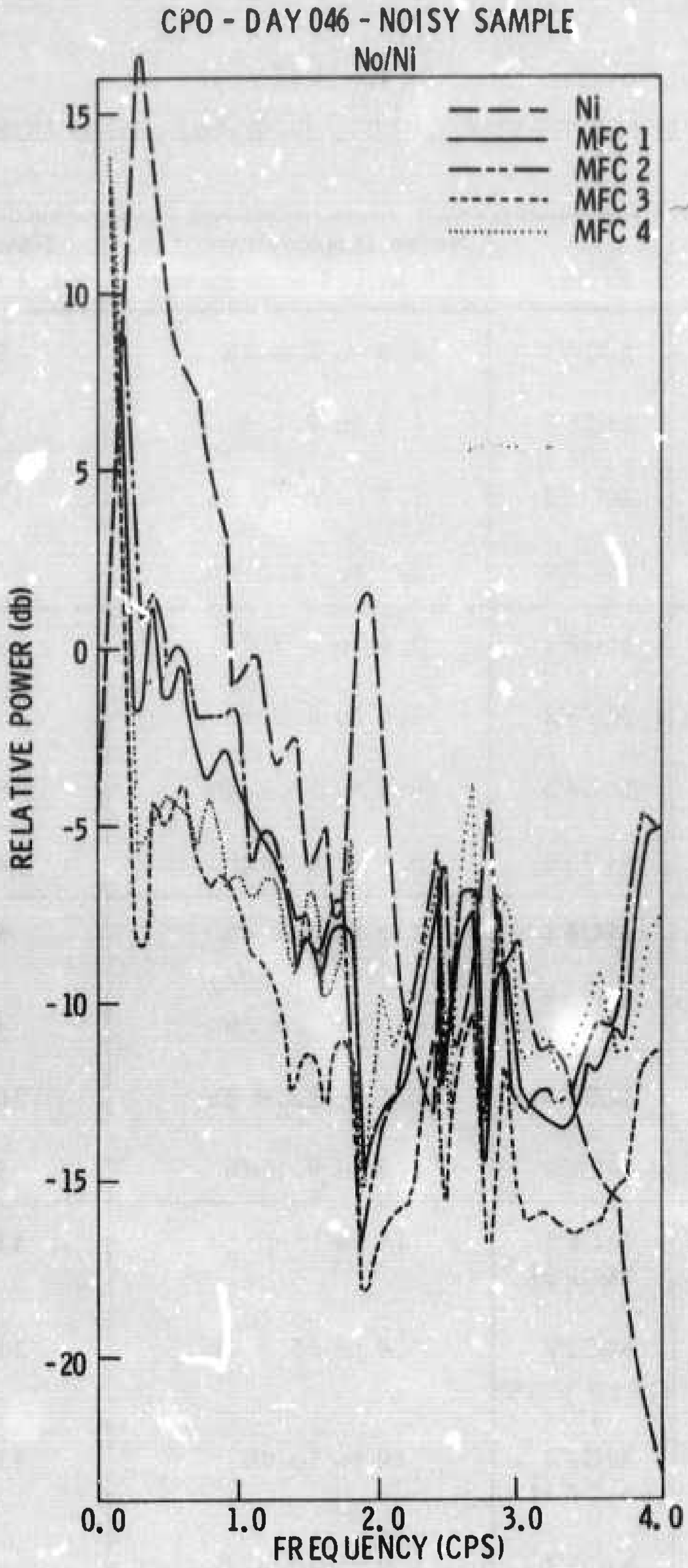


Figure IV-12. N_o/N_i Curves for Day 046 - Noisy Sample

Table IV-7

NOISE IMPROVEMENTS FOR QUIET, NORMAL, AND NOISY SAMPLES

Noise Type	Filter	Noise Improvement (0.6 to 1.4-cps range)	Noise Improvement (1.4 to 4.0-cps range)
Low level (Figure V-2)	MCF1	2.5 to 7.0 db	5.1 to 14.2 db
	MCF2	2.5 to 7.0 db	3.7 to 14.2 db
	MCF3	5.7 to 17.0 db	11.5 to 18.0 db
	MCF4	5.1 to 11.5 db	1.9 to 12.4 db
Average level (Figure V-3)	MCF1	3.0 to 8.7 db	3.5 to 15.0 db
	MCF2	3.0 to 8.7 db	4.3 to 15.6 db
	MCF3	6.0 to 12.6 db	8.6 to 18.6 db
	MCF4	5.8 to 8.3 db	6.3 to 16.7 db
High level (Figure V-4)	MCF1	1.8 to 8.9 db	5.1 to 15.2 db
	MCF2	0 to 7.5 db	4.7 to 16.9 db
	MCF3	3.9 to 12.4 db	10.5 to 18.2 db
	MCF4	4.7 to 9.0 db	3.7 to 15.2 db
Off-line analysis	MCF1 (MCF3)	10 to 16 db	11.3 to 21.4 db
	MCF2 (IP10 WGS)	8.9 to 15.9 db	11.1 to 19.6 db
	MCF3 (MCF3)	10 to 16 db	11.3 to 21.4 db
	MCF4 (MCF24)	7.3 to 10.4 db	8.3 to 12.7 db

obtaining good noise suppression consistent with previously developed off-line data. However, indications are that there may be small inaccuracies in the on-line processed data, for example:

- MCF1 and MCF3 results should be identical once frequency-filtering effects are removed
- From previous results MCF3 and IP10 WGS should produce comparable results on the average, which is not the case here

The discrepancies seem to be in data which has had frequency filtering effects removed (MCF1 and MCF2). It is suspected that there may be a 3 to 4 db error in this data, but attempts to confirm this were unsuccessful.

In summary, the data indicates that the MCF was obtaining the expected improvement in noise suppression on all trace outputs if the assumption regarding MCF1 and MCF2 is correct. In the primary signal frequency band of 0.6 to 1.4 cps from 3.0 to 17.0 db improvement was obtained, and at higher frequencies of 1.4 to 4.0 cps from 1.9 to 18.2 db of improvement was obtained for the samples studied.

To compare the output of the processor with a standard output (single trace, ΣT-straight sum, ΣTF-straight sum bandpass filtered 1.0 through 2.0 cps with 18 db/octave slope), microseism curves were computed for the processor's output. This section presents the results of the comparison.

The comparison between MCF1 and MCF2 and ΣTF and the comparison between MCF3 and MCF4 and ΣT are important in this study. Figures IV-13 and IV-14 present the comparison between MCF1 and MCF2 and ΣTF with Z-8 included as a reference trace. Figures IV-15 and IV-16 present the comparison between MCF3 and MCF4 and ΣT with Z-8 again included for a reference trace.

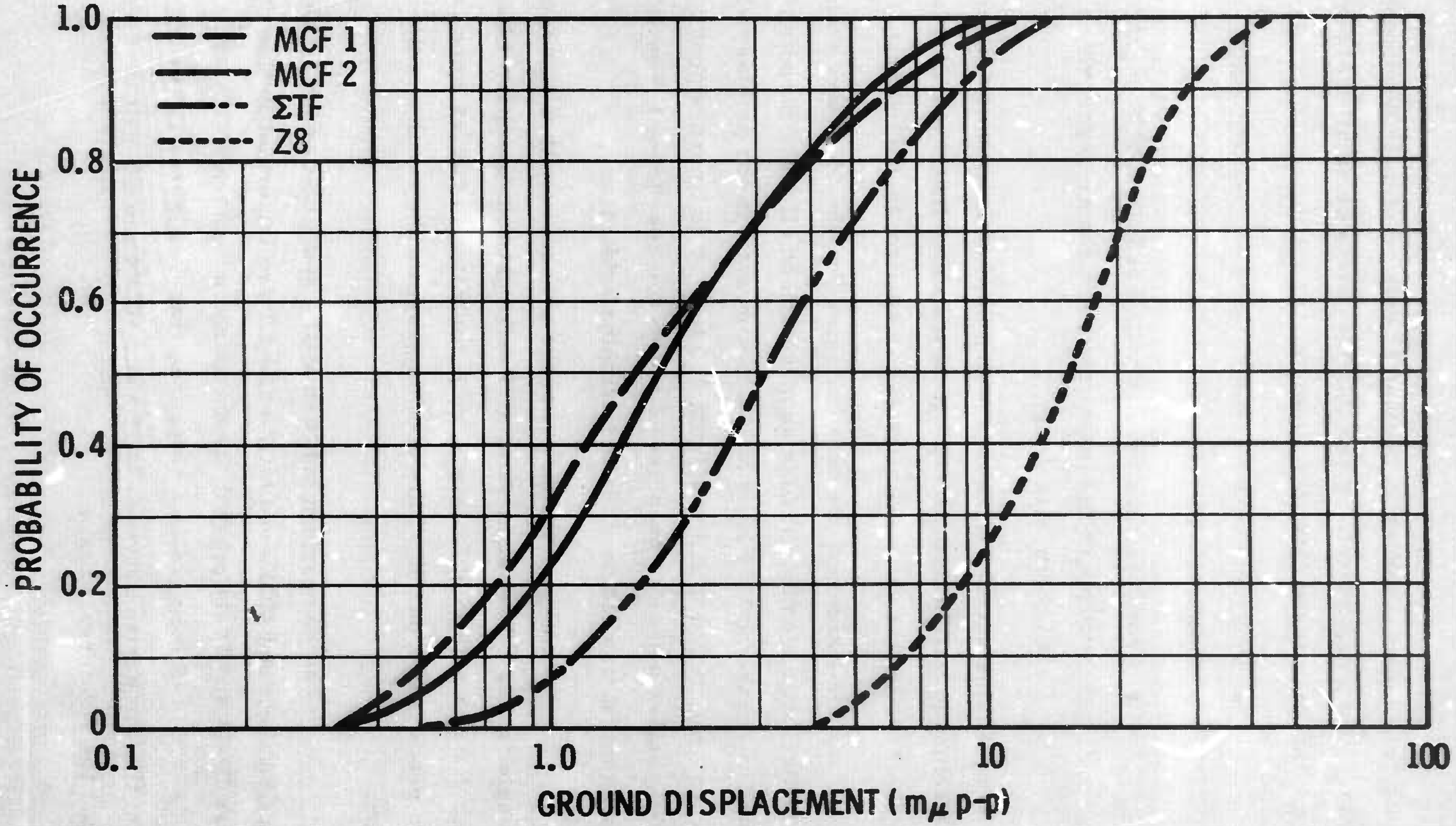


Figure IV-13. Probability of Microseisms in the 0.4- to 1.4-sec Period Range Occurring at or Less Than a Given Ground Displacement at CPSO during January 1967

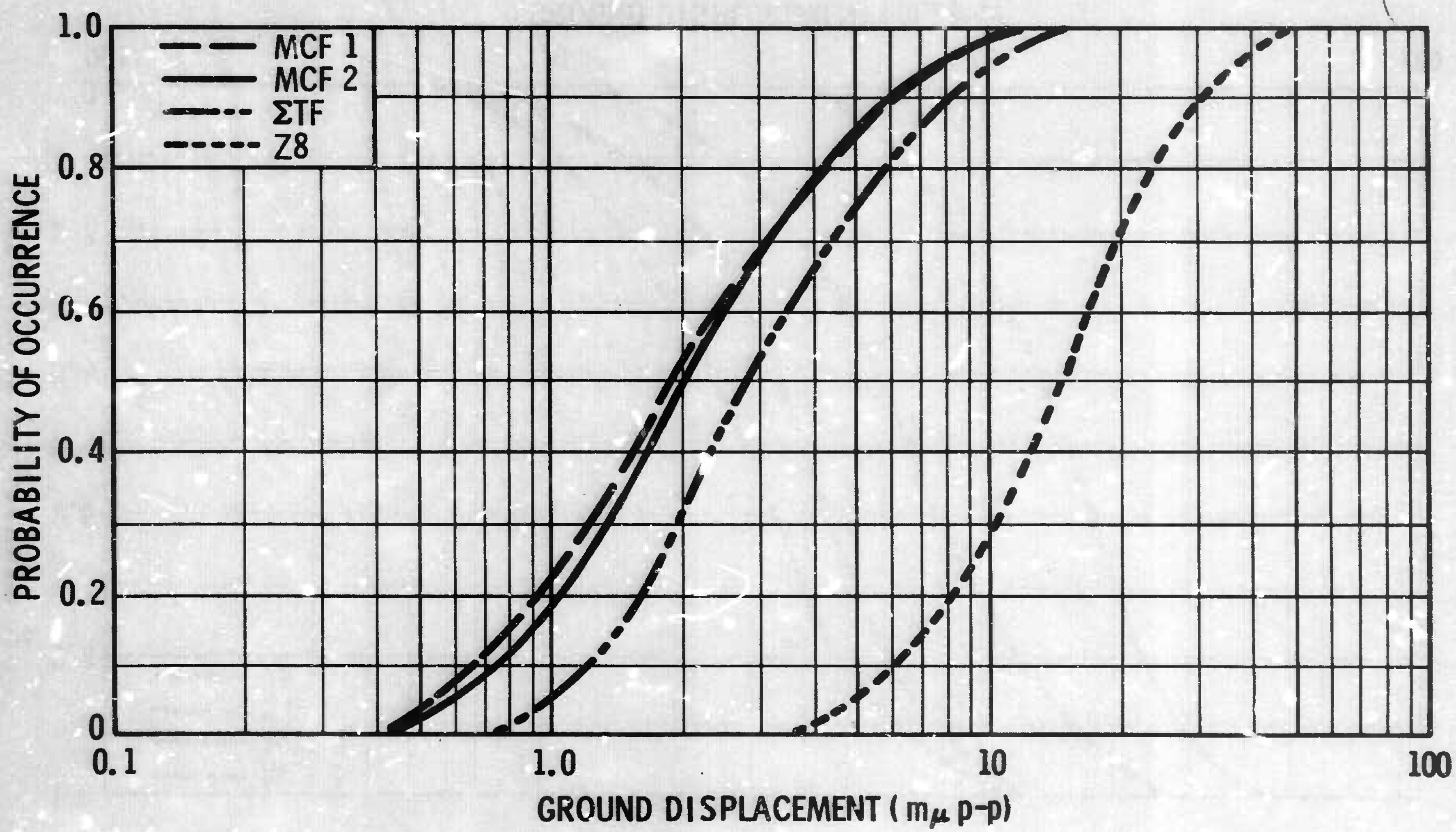


Figure IV-14. Probability of Microseisms in the 0.4- to 1.4-sec Period Range Occurring at or Less Than a Given Ground Displacement at CPSO during February 1967

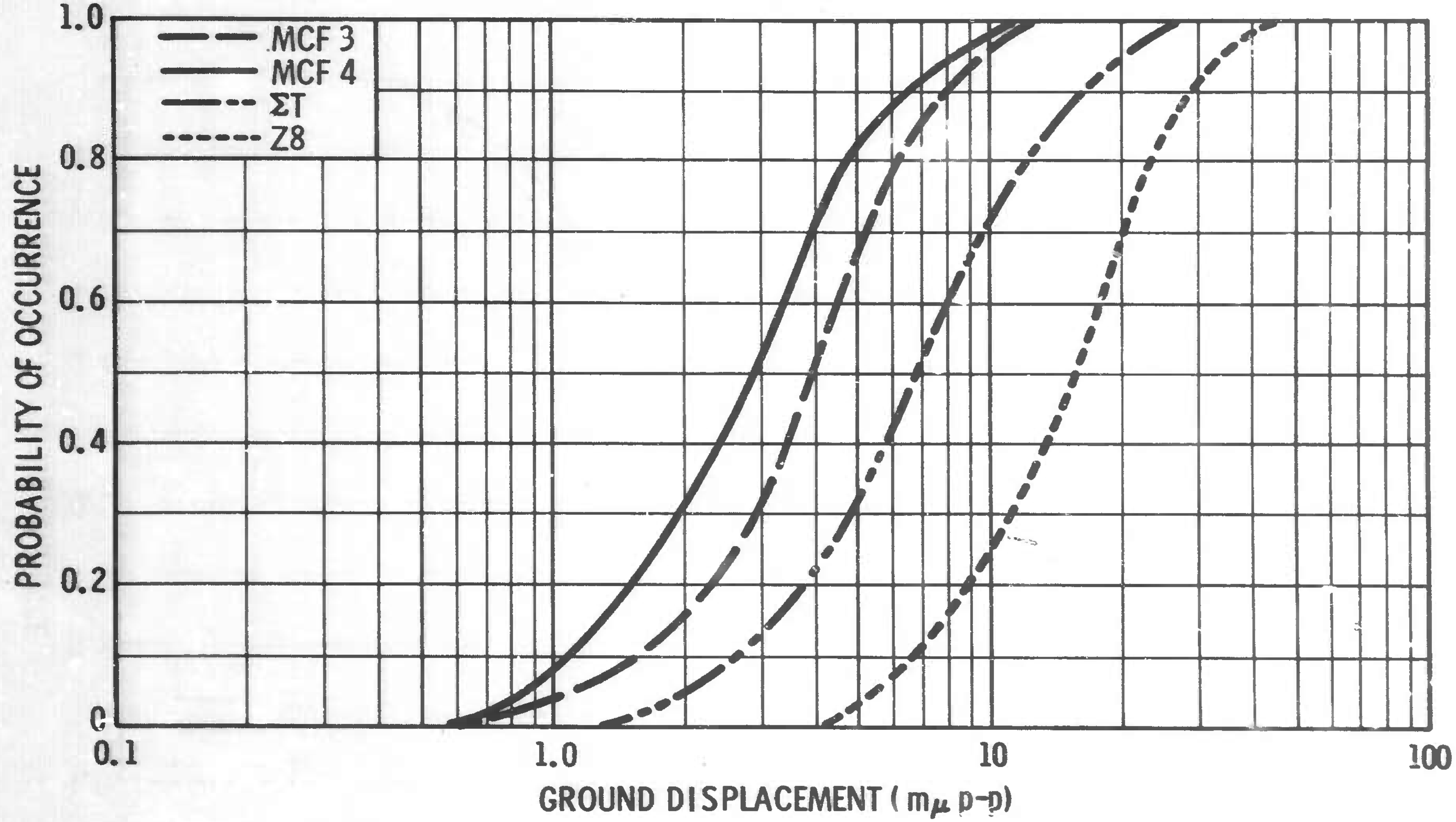


Figure IV-15. Probability of Microseisms in the 0.4- to 1.4-sec Period Range Occurring at or Less Than a Given Ground Displacement at CPSO during January 1967

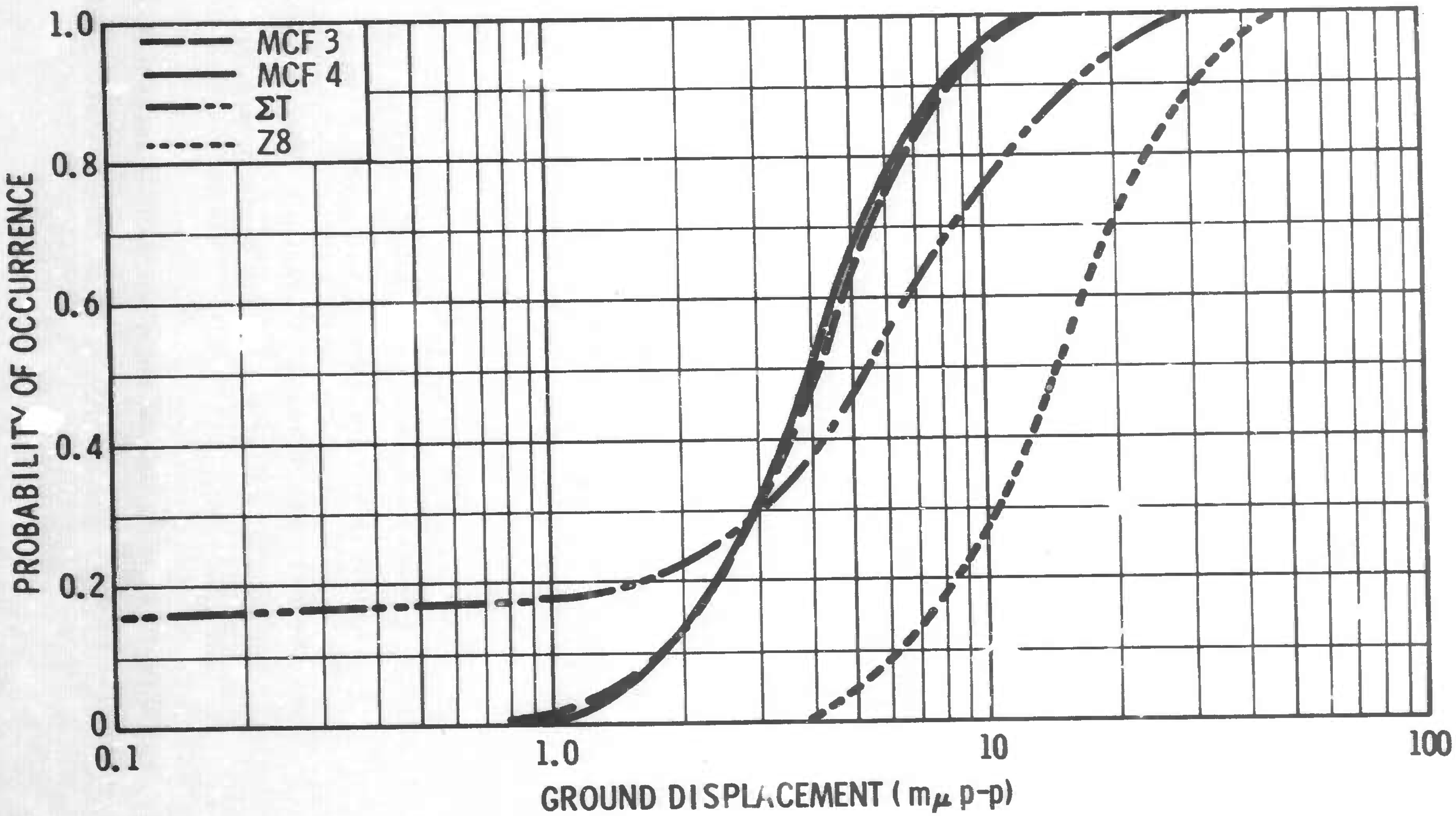


Figure IV-16. Probability of Microseisms in the 0.4- to 1.4-sec Period Range Occurring at or Less Than a Given Ground Displacement at CPSO during February 1967

Figure IV-13 shows a 6.0 db improvement at the 50-percent level when comparing MCF1 and MCF2 with ΣTF trace. Similarly, Figure IV-14 shows a 3.3-db improvement for the MCF's. Figure IV-15 shows a 7.3-db improvement at the 50-percent level when comparing MCF3 and MCF4 with the ΣT trace. Similarly, Figure IV-16 shows a 2.4-db improvement for the MCF's. Averaging the results for the four figures gives an MCF improvement of 4.75 db. Therefore, it is obvious that the MCF's are better than the ΣT and ΣTF traces for signal detection in the presence of microseismic activity.

5. Conclusions and Recommendations

Based on the analysis of the processor operation during the two contract years, the following conclusions have been reached:

- The processor may be operated by trained analysts, as was done at CPO for the last 4 mo. of the contract
- The processor may be maintained by a trained technician
- Use of the processor indicates empirically a personnel decrease of one person required in the station analysis section as a result of increased ease in detecting events and in identifying event phases and direction
- At the CPO site, no apparent need was evident which warranted the updating of the MCF's since consistent noise suppression was found during both contract years
- The processor increased the analysts' detection capability, but the CPO station still did not report events from the northern hemisphere

From this study several recommendations based both on the results obtained from evaluating the data in the seismic research areas in

the Dallas center and from analysts' evaluation of the processor as an aid in event detection, are

- Primary on-line evaluation should be performed using the MCF data rather than secondary or primary data. Increased MCF S/N improvement has a definite impact on station-detection capability.
- Use of the beam-steer capability in small arrays is useful even when resolution is limited. Analysts stated that when the additional beam-steer traces were compared with each other and with the four MCF output traces, they gave a better indication of the presence of events, and verified the presence of a suspicious signal or phase carried on all the traces. Also, some useful resolution is obtained for low-velocity signals from local or regional events.
- The bandpass filter used at CPO had too narrow a passband and was limiting analysis, since it was rejecting a significant portion of some signals. A passband of 0.6 to 2.0 cps is recommended.
- All beam-steer and MCF outputs should use frequency filters with the same passband.

B. AUXILIARY PROCESSOR

1. Description

The design philosophy and general appearance of the Auxiliary Processor was modeled after the MCF processor. The unit is composed on an 80-in. single bay rack containing arithmetic, output and controller drawers. The spare rack space in the Auxiliary Processor may be used for support equipment, such as the paper tape reader or other test equipment.

All input data signals are derived from the basic MCF as follows: the Wiener power process derives its input from the MCF1-4 outputs, the Fisher process accepts single-channel data from the MCF0 output, and the UK process derives its input from two selectable beam-steer outputs.

The processor outputs are converted from digital-to-analog using the same type converter as those used in the MCF processor. The processor outputs are summarized as:

- One Fisher output trace
- Two UK output traces corresponding to two programed area locations
- Four Wiener power traces corresponding to the MCF1-4 output traces
- One Fisher threshold trace corresponding to the Fisher output trace
- Four Wiener threshold traces corresponding to the four Wiener power traces

The program selection for the processor is determined by several panel-mounted switches. The following variables may be programed:

- Fisher Process

  Normalization constants N1 and N2 are variable from 0 to 777_8. History length (gate length of computation) may be selected from 0 to 999 points.

- UK Process

  History length is variable from 0 to 999 points, and selection of the 4 beam-steers (2 each for UK0 and UK1) is provided.

- Wiener Power Process

  History length specifiable in R intervals, 0 to 99, and S samples, 0 to 99, where the gate is determined by R intervals of S samples each.

- Threshold Detectors

  Independently variable threshold levels are programable from 0 to 777_8.

2. Operation

Once the Auxiliary Processor system was initially programed, adjustment was limited to daily changes of the threshold-level detection switches for the Fisher and Wiener outputs. However, several problems were encountered in the initial programing. These were determining the input data truncation switch for the Fisher Process, the Fisher intermediate summation truncate switch, the Fisher transform constant N2, and the method for accurately setting the threshold level switches. Recommendations for simplifying the set-up and operation of the system are presented in Section IV-B4.

The Auxiliary Processor was operational on-line at CPO from 30 December 1966 to 10 April 1967. Table IV-8 presents a summary of the fixed program employed in the digital MCF and Auxiliary Processor during this time period. Table IV-1 presented a summary of the MCF's and beam-steers employed in the processor.

3. Hardware Evaluation

The CPO Auxiliary Processor is a highly reliable digital processing device. During its operation at CPO (over 3 months) not one failure occurred. This represented an operating time of approximately 2900 hr. For future operations this unit should continue to be quite reliable

Table IV-8

PROCESSOR PROGRAM DATA

MCF PROCESSOR

Channels	19
Filter points	57
Multichannel filters	5
Beam-steers	9
Signal conditioner	All 0's
D-A converter	Channels 0 to 4 = -3 Channels 11 to 14 = -3
Beam-steer history	15
Time delay	28

AUXILIARY PROCESSOR

Arithmetic drawer	UK0	56
	UK1	78
	UK history	60
	Fisher N1	777_8
	Fisher N2	20_8
	Fisher history	60
	MCF Power	R = 60, S = 1
Output drawer	UK0	-3
	UK1	-3
	MCF0	-4
	MCF1	-4
	MCF2	-3
	MCF3	-3
	Fisher	-15
Data trucate switches	Fisher	-3
	UK	-2
	MCF power	-2
Fisher summation truncate switch		-7

Note: Threshold switches were varied on a daily basis.

since it consists entirely of solid-state hardware with the exception of the blower motor.

Little maintenance experience was gained on the unit due to its high reliability. Once installation and operational checkout was complete, processor maintenance was limited to routine operations.

During the on-site installation and checkout, some knowledge of the processor maintenance was gained. The following conclusions were drawn from this limited experience:

- The processor can be maintained by an individual trained in MCF maintenance if he reads and understands the handbook
- The computer wire list provided with the system is adequate but cumbersome to use

4. Technical Evaluation

a. Automatic Detection

Two problems were encountered at CPO in implementing and evaluating automatic on-line detection with the Auxiliary Processor system. One problem was that the defined detection threshold for a fixed false-alarm rate was highly variable. The other was that the method used for determination of the threshold levels was inaccurate and cumbersome.

These two problems interrelate since the time variability problem could have been partially overcome by adjusting the detection threshold settings often, but a rapid and accurate technique for determining the desired threshold level for a fixed false-alarm rate was not available with the existing hardware and setup. The inaccuracy of the threshold determination techniques could have been overcome by record[illegible] outputs on FM tape and conducting off-line analysis to determine the de[illegible]d levels, but this was

useless due to the non-time stationarity of the Fisher and Wiener power output noise distribution.

A procedure was adopted at CPO to update the threshold levels on a daily basis. This procedure established an approximate representation of the output noise distribution in terms of the daily threshold-level setting.

Exact cause of the variation in output levels is not known at this time; however, it is reasonable to suspect several sources. In the case of the Fisher process, changes in the mantle P-wave noise level and in the level of the trapped-mode noise are probably the most significant contributors. Mantle P-wave noise variability as well as changes in trapped-mode noise direction could affect the Wiener detection outputs.

Results from the CPO noise analysis indicated that the predominate trapped-mode noise components remained stationary over the analysis period. However, indications were that the intensity of the various components varied; such a variation would reasonably affect the Fisher distribution.

Determination of the desired threshold level for the Fisher and Wiener power outputs would normally be based upon a fixed false-alarm rate which could be determined from knowledge of the detection output distribution values, assuming that the distribution remains stationary over a reasonable period, such as a season. Under this assumption, off-line processing of detection output data would be reasonable to determine the amplitude distribution and subsequently the desired threshold. Detection output data could be collected on FM tape, digitized and the distribution computed.

Since the apparent amplitude distributions at CPO were non-time stationary over periods as short as hours, ruling out off-line processing for level determination, an on-line procedure was established

which, in effect, was a trade-off between accuracy and speed. This procedure, although performed daily and more often if required, proved to be inadequate to handle the non-time stationarity problem. Probably this was due in part to inaccuracy.

The procedure determined the mean amplitude value from a 5-min period of noise using five noise measurements at approximately 1-min intervals. Each measurement was made over 10-sec of data and involved determining the amplitude value of the peaks and troughs and arranging them to obtain a mean output level. The five measurements were arranged to determine the daily mean value for each detection output. The mean was then multiplied by a constant to determine the threshold value. Several constants were tried, based upon an assumed distribution, with the constant 2.5 determined best from observed data.

In practice, this technique was limited by the absence of an accurate vertical scale on the Develocorder. A make-shift scale was applied to the film by placing the output D-A switches for the Fisher and Wiener power outputs in the "+" and "0" test modes. This produced a zero and maximum value (777_8) on the film which could be used as a scale. When in this test mode, Fisher and Wiener power data are not output.

Since problems were encountered using the automatic detection thresholds, an attempt was made to analyze the Wiener power and Fisher outputs for detection purposes. This proved to be unsatisfactory to the station analysts because the effect of smoothing of the integration gate destroyed signal energy content and waveform, and made the transition from noise to signal areas for small events quite gradual contrasted to the normal sharp break detectable for a P-wave arrival. Also, the "event signatures" which were commonly used to detect low-level signals were not easily recognized after detection processing.

In addition, the absence of a zero level for each of the traces

made it difficult to determine visually relative amplitude on the trace data.

Limited comparisons of the Fisher and Wiener power processing at CPO were made by the observatory analysts while attempting to analyze these data for event detection, including:

- For high velocity signals, the ratio of the peak signal output to the RMS statistic is larger for the MCF processes than for the Fisher output (Figures IV-17 and IV-18)
- The Fisher signal response to quarry blasts shows the Fisher outputs to be unaffected by P- and S-wave energy falling in the velocity ranges 6.1 to 8. km/sec and 3.25 to 3.51 km/sec, respectively (Figure IV-19)

The Fisher signal response property was also investigated in off-line research (Section V) and found to decrease rapidly with increasing wavenumber. This property proved quite useful at CPO for distinguishing local and near regional events from teleseismic P-wave energy and on several occasions aided in detecting teleseismic P-wave energy during quarry-blast arrivals.

b. Classification

Analysis of the two UK outputs at CPO indicated that the British Classification scheme could be effectively applied on-line. However, three limitations exist, two caused by the present implementation and the other caused by CPO noise properties. These limitations are

- The two UK outputs are computed from a fixed program which in essence restricts classification work to two signal sources. At CPO the outputs were computed for NTS and for Russia.

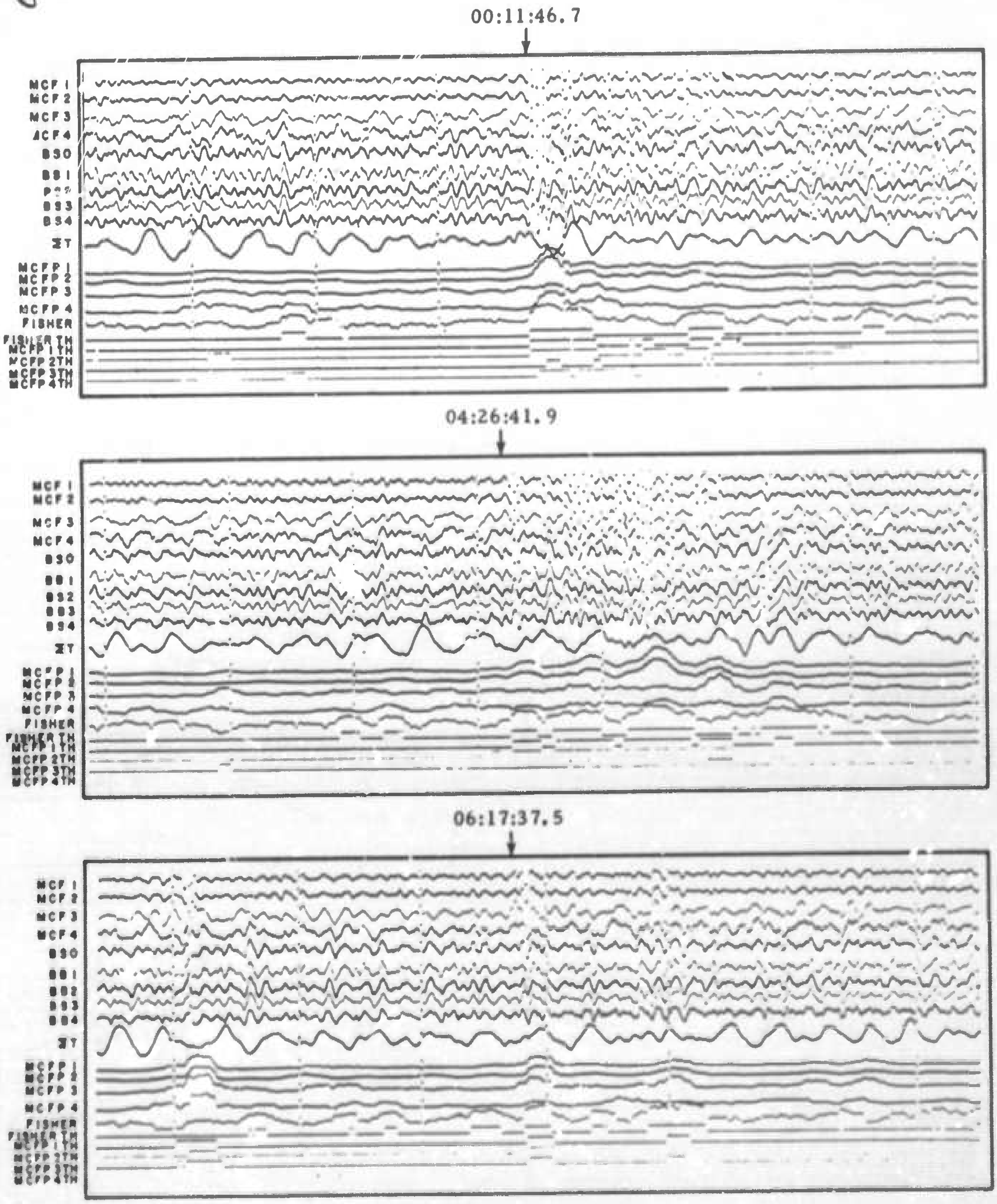


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Figure IV-17. Data Processed by the MCF and Auxiliary Systems During Known Signal Conditions

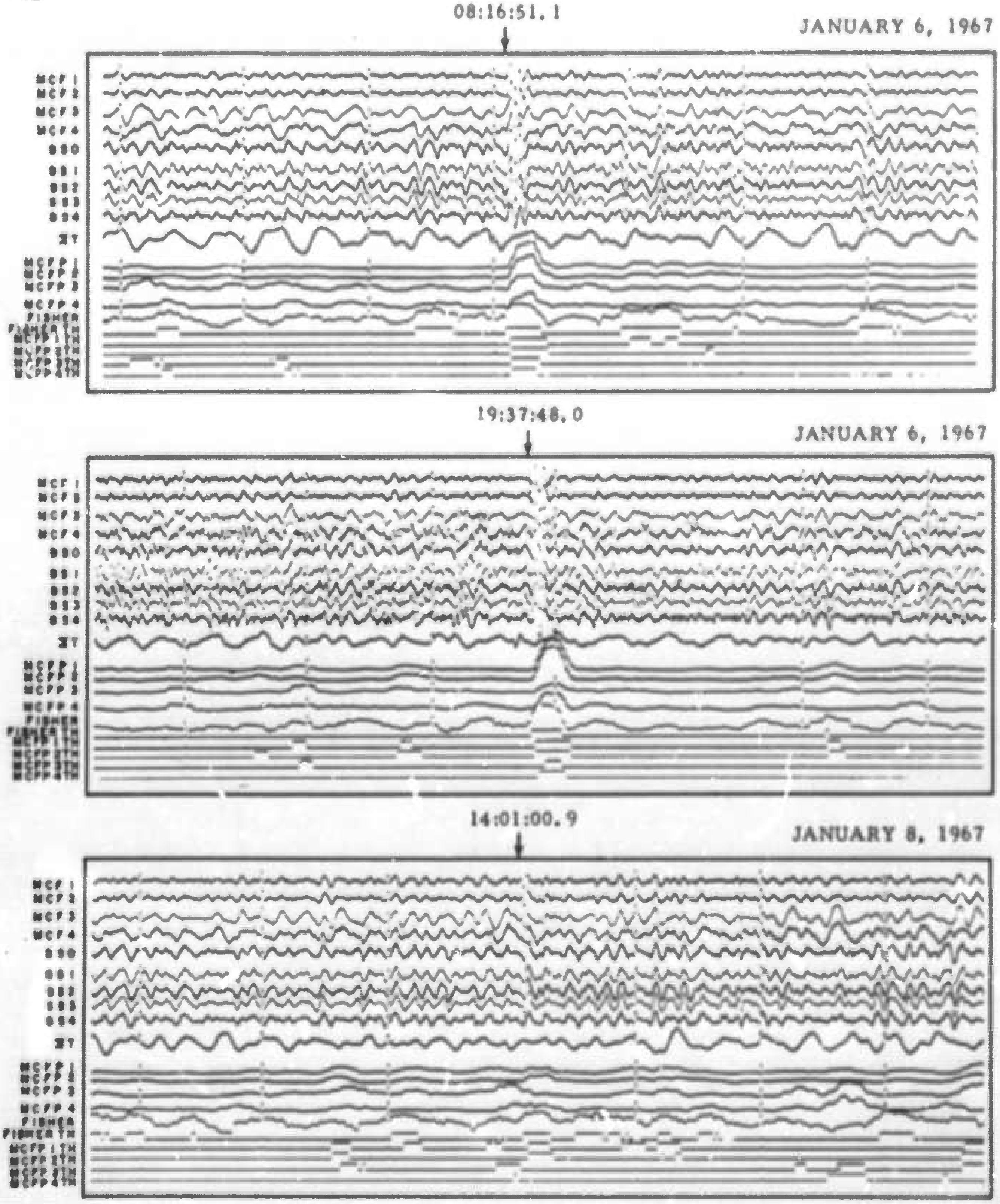

Figure IV-18. Data Processed by the MCF and Auxiliary Systems During Known Signal Conditions

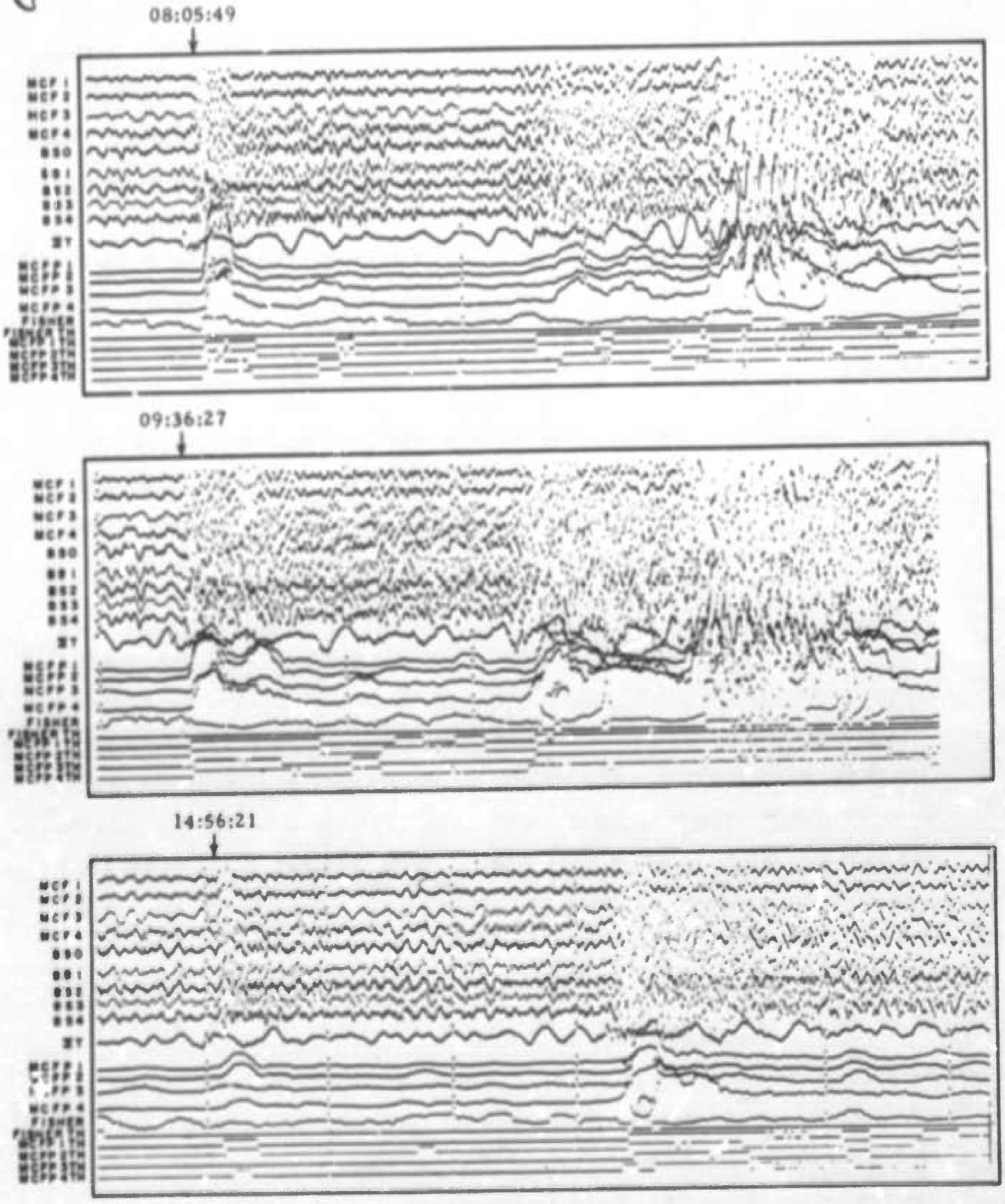

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Figure IV-19. Three Quarry Blasts Processed by the MCF and Auxiliary Systems

- Classification based upon the UK scheme requires preservation of signal waveform. The MCF — Auxiliary Processor system is limited to 72-db dynamic range on input (12 bits). Since this system is used primarily for detection based upon suppression of coherent noise, the input noise level must be sufficiently high to insure adequate noise statistics for MCF processing. Thus, large signals are clipped on input or during intermediate computations.
- The UK technique is designed for application to intermediate size crossarray data (approximately 20 km) to insure adequate resolution and an uncorrelated ambient noise field. The CPO array (3.6 km dia) violated the assumption of uncorrelated noise and provided very poor directional velocity resolution.

At CPO the UK portion of the processor was programed for maximum waveform preservation within the limitation of having the input data gain setting optimized for MCF programing. Thus, the UK input data truncation switches were set such that a 12-bit signal on input to the MCF (maximum P-P without clipping) would be processed by the UK computation and output without clipping. This set-up was considered optimum for the classification computation since waveform preservation is most important. However, with the Develocorder adjusted to a measurable gain level, modulation of low-level signal was poor.

Because of the limitations discussed above, sufficient data were not collected under this task to conduct a study of the UK classification scheme. Considerable information for advancing the state-of-the-art real-time automatic detection processing was gained by the implementation and evaluation of the CPO Auxiliary Processor. Both the Wiener power and Fisher statistic computations appear to be useful for detection purposes,

but completely automatic detection should be accomplished with an adaptive threshold device. Such a device can be easily incorporated into the existing hardware with a relatively minor modification.

Little information was gained from computation of the UK technique on-line at CPO. The adverse array properties and dynamic range problem coupled with the sparseness of desired events severely limited the necessary library of events required for this study.

Off-line Dallas-supported research complemented the on-line evaluation and provided a more comprehensive understanding of on-line Fisher and Wiener automatic detection processing.

In order to simplify initial set-up and operation of the Auxiliary Processor system, the following changes are recommended for possible future systems. Most of these could be easily incorporated into the existing hardware with only minor modifications. The threshold detector change is considered essential for proper operation of the systems as an automatic detection device. Recommended changes are

- Setting the Fisher transform constant N1 to a fixed value of 777_8 in order that the maximum Fisher output value will equal the maximum output number (9 bits). Gain control would still be available in the Fisher D-A switch.
- Setting the Fisher transform constant N2 to a fixed value of 20_8 since, from what is now known about the expected size of F for array data, this value insures adequate number significance between true Fisher values and transformed Fisher output values.
- Providing a test mode for displaying the Fisher intermediate terms K1, K2 and K3 in order to facilitate

setting the Fisher input and intermediate data truncation switches. These terms could be displayed on the Wiener power outputs when in the test mode.

- Providing an input channel selection capability for the Fisher input. At present all MCF input channels used in any beam-steer output are used in the F computation. For example, if it were desired to input a 3-component sensor to the MCF for the purpose of frequency filtering, delaying and displaying adjacent to the MCF data, these inputs would currently be included in the F computation.
- The threshold level switches for the Wiener and Fisher outputs should be modified to be adaptive rather than fixed outputs. A suitable approach would be the incorporation of an adaptive threshold device into the existing hardware which could be made to adapt to data history, thus insuring a relatively consistent false-alarm rate.

By using an on-line adaptive algorithm to update the threshold levels constantly, problems in measuring distribution, etc. could be avoided. Only the specification of a constant multiplier to be applied to some output property such as the mean value would be required.

CPO Special Report No. 5[2] presents an adaptive threshold algorithm which is recommended for incorporation into the existing Auxiliary Processor.

SECTION V
RESEARCH

Research conducted during the last contract year primarily supported on-line operation of the MCF--Auxiliary Processor system and included a continuation of the ambient noise study begun during the first contract year under VT/5054 and an off-line investigation of detection processing to include optimum parameter specifications and applied Fisher research. In addition, a task was undertaken to enhance the visual display of seismic data.

The following paragraphs discuss each of these three tasks. In the case of the ambient noise study and the detection processing, research results are only summarized since details of these tasks have been documented in CPO Special Reports No. 1 and 5, respectively.[6, 2]

A. AMBIENT NOISE STUDY

The ambient noise study was directed toward determining the detailed configuration of the noise structure at CPO, with particular emphases placed upon the time stability of the noise. Knowledge of the noise structure as a function of time is necessary for optimum operation of the MCF system which performs Wiener signal extraction processing based upon suppression of coherent noise. The effectiveness of this type of processing depends upon the noise statistics used initially to synthesize the filters.

If the ambient noise structure remains stationary in time (and the statistics used in filter synthesis adequately described this structure), then the MCF will perform optimally over extended periods. However, if the ambient noise structure changes in time, the filters must be synthesized to include the statistics of this change.

Investigation of the CPO noise properties began the first contract year (VT/5054) and was continued during the second year (VT/6704). Results

of the two year study of absolute-noise power-density spectra, spatially organized low-velocity noise and spatially organized high-velocity noise will be included in this report for reference purposes.

1. Single-Channel Ambient-Noise Power-Density Spectra

Single-channel power-density spectra were computed on a daily basis during the period 1 May 1965 through 31 October 1965 and on a weekly basis from 1 November 1965 through 31 October 1966. These spectra were computed from 6.33 min of noise recorded at the center seismometer of the array during various hours of the day. The 1.0-cps ambient-noise energy for this period averaged approximately 1.0 $m\mu^2$ of the ground motion/cps with variations as large as ±7 db. Variations in the power density spectra were studied over various time periods and hypotheses for the source of the variations were formulated.

To study the periodic variations in the noise field, power-density spectra were computed hourly over a 48-hr period (Figure V-1). These spectra did not exhibit any large periodic changes in shape. However, in this study some minor variations in power were observed at several defined frequencies or frequency bands and are probably attributable to cultural activity near the station (Figure V-2).

The largest variation in power, occurring at 1.4 cps, could not be restricted to any consistent time period and appears to be randomly generated by a cultural or natural source to the northwest of the array. Only at 1.5 cps could a slight, regular increase in the noise level be correlated with increased cultural activity.

As shown in Figure V-3 studies for longer periods of time exhibited noticeable variations at frequencies below 1.5 cps. These have been correlated with the development of low-pressure areas off the Atlantic and Gulf of Mexico coastlines. A direct correlation was noted between the

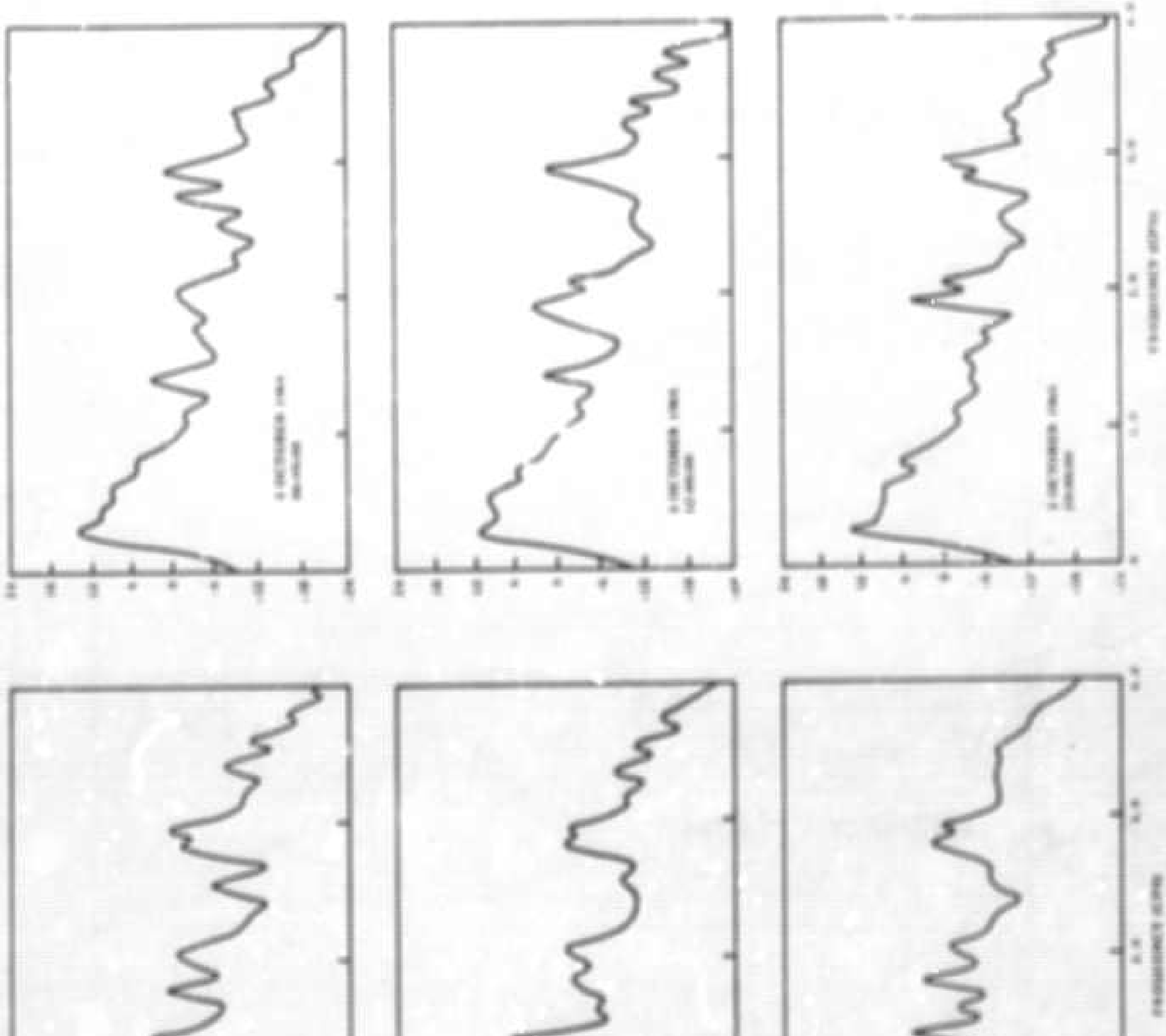


Figure V-1. CPO Ambient Noise Power Density Spectra for 2 October 1965 and 3 October 1965

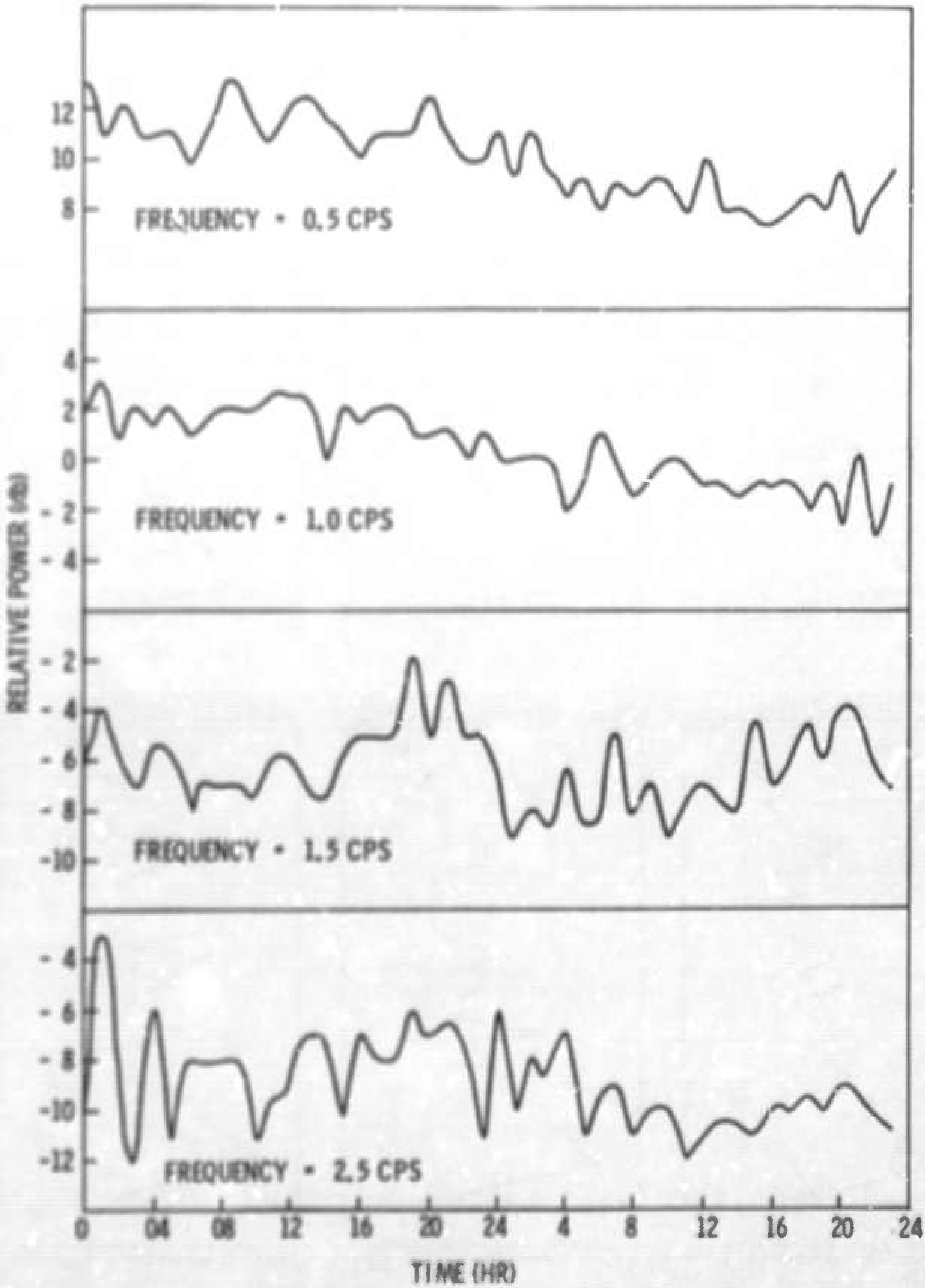


Figure V-2. CPO Noise Power Variations Over a 48-Hr Period

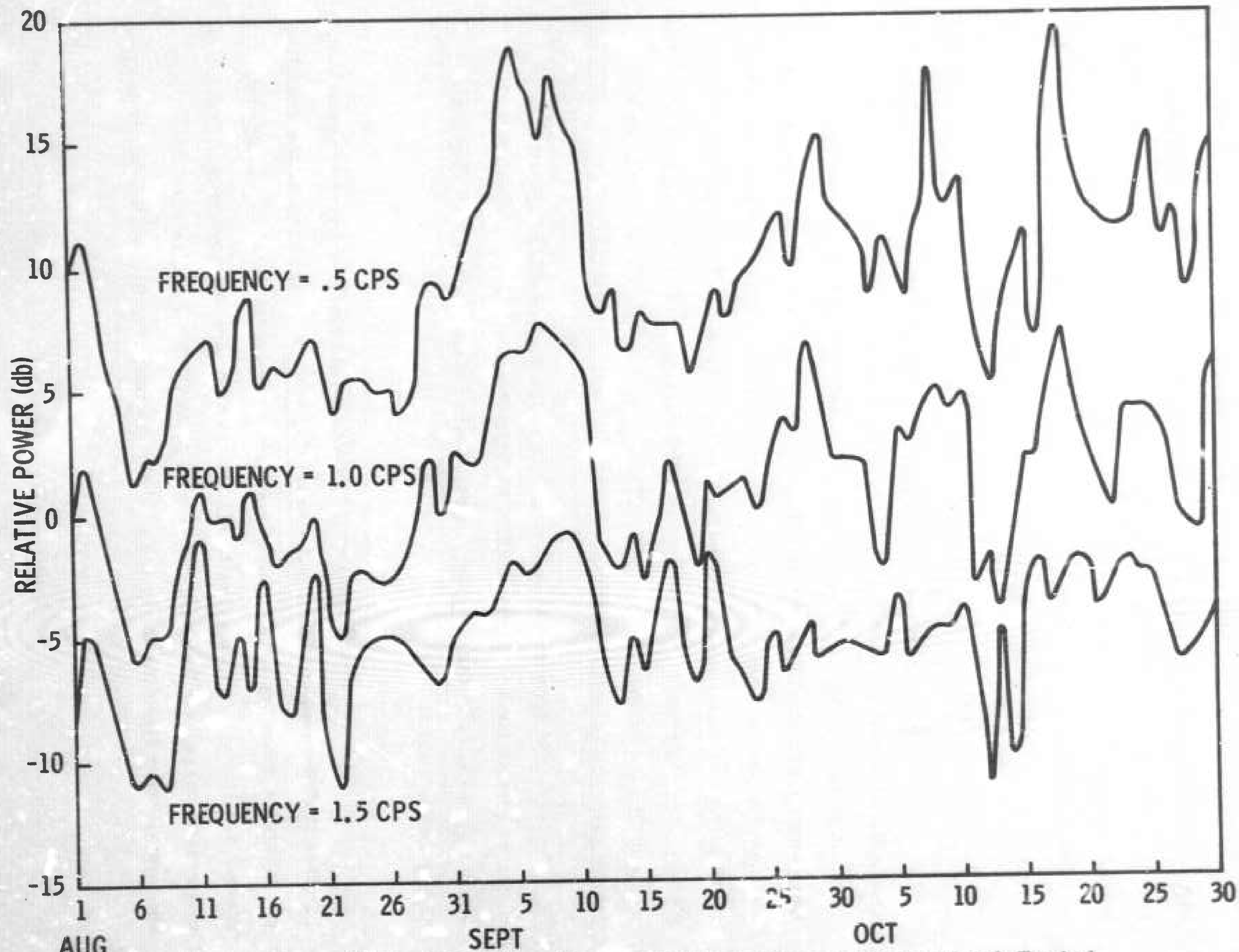


Figure V-3. CPO Noise Power Variations Over a Three-Month Period

intensity of the low-pressure areas and the increase in power at the lower frequencies. Fluctuations in the power level were also noted in the frequency band 2.25 to 2.75 cps and were probably due to local cultural activity and weather conditions.

2. 3-Dimensional Noise Power-Density Spectra

Analysis of the 3-dimensional noise power spectra for CPO shows that several spatially organized noise sources exist in the frequency range 0.25 to 2.25 cps. To show that the spatially organized noise field has remained time-stationary over the extended time period of 1963 through 1965 except for changes which occur during periods of low pressure and when tropical storms exist at sea, Figures V-4 through V-8 are presented. Figure V-4 presents spectra for the 1963 data, and V-5 through V-8 present 18 sets of spectra for 1965. These spectra clearly show the time stationarity of the noise field.

At frequencies below 1.0 cps, the main contributor to the organized noise field is high-velocity mantle P-wave energy and noise generated in the area of the Atlantic Coast, Gulf of Mexico, and possibly the Great Lakes region.

Narrowband filtered playbacks of the ambient noise (Figure V-9) indicate that the long-period energy traveling from the direction of the coastline propagates across the array with an apparent horizontal velocity of approximately 3.2 km/sec. This velocity closely agrees with the previously developed dispersion curves for Rayleigh-wave energy at CPO. Results also show that the contribution from the direction of the coastline becomes significantly large

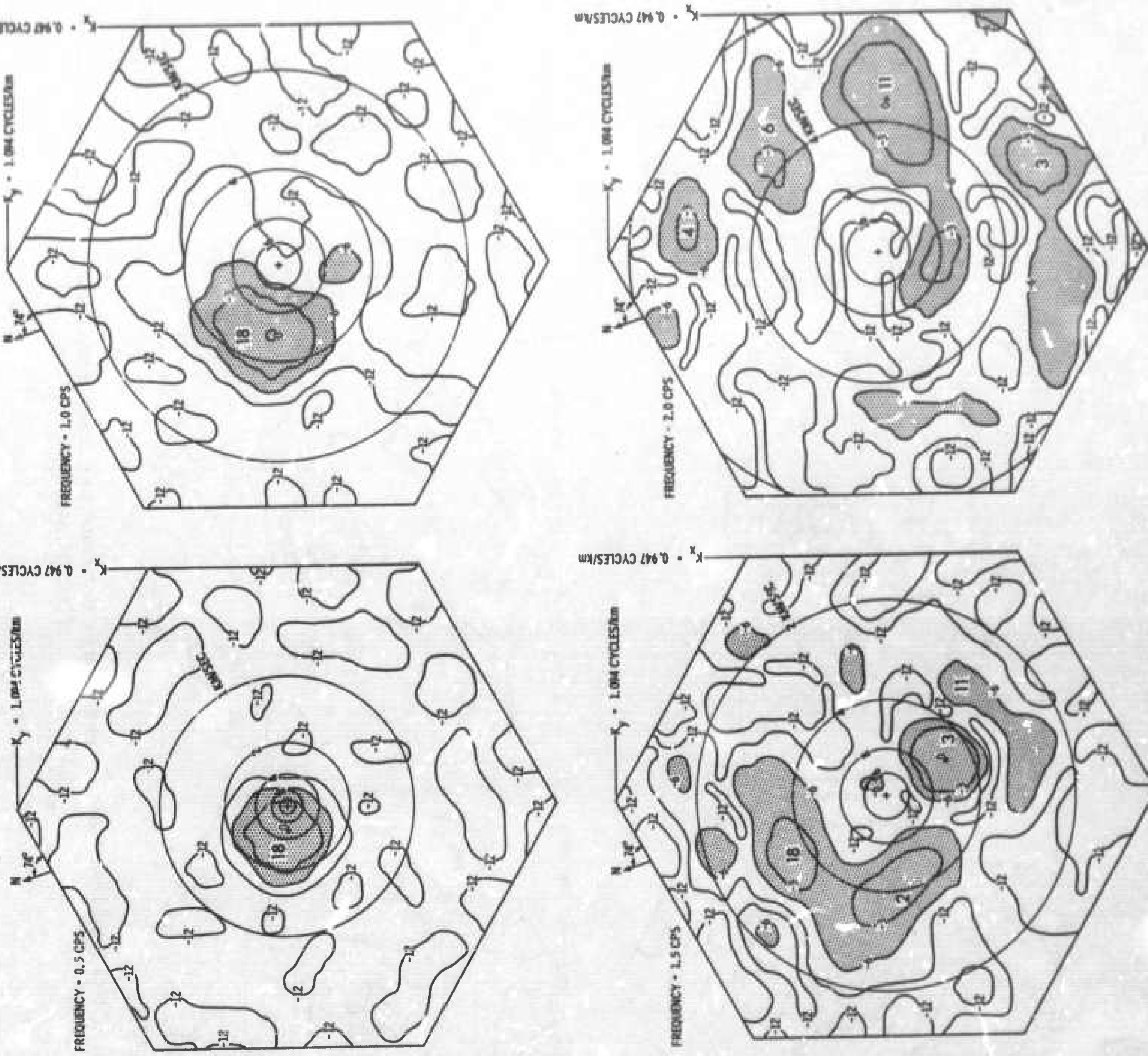


Figure V-4. CPO Ambient Noise Frequency-Wavenumber Spectrum, 1963 Average Noise Sample

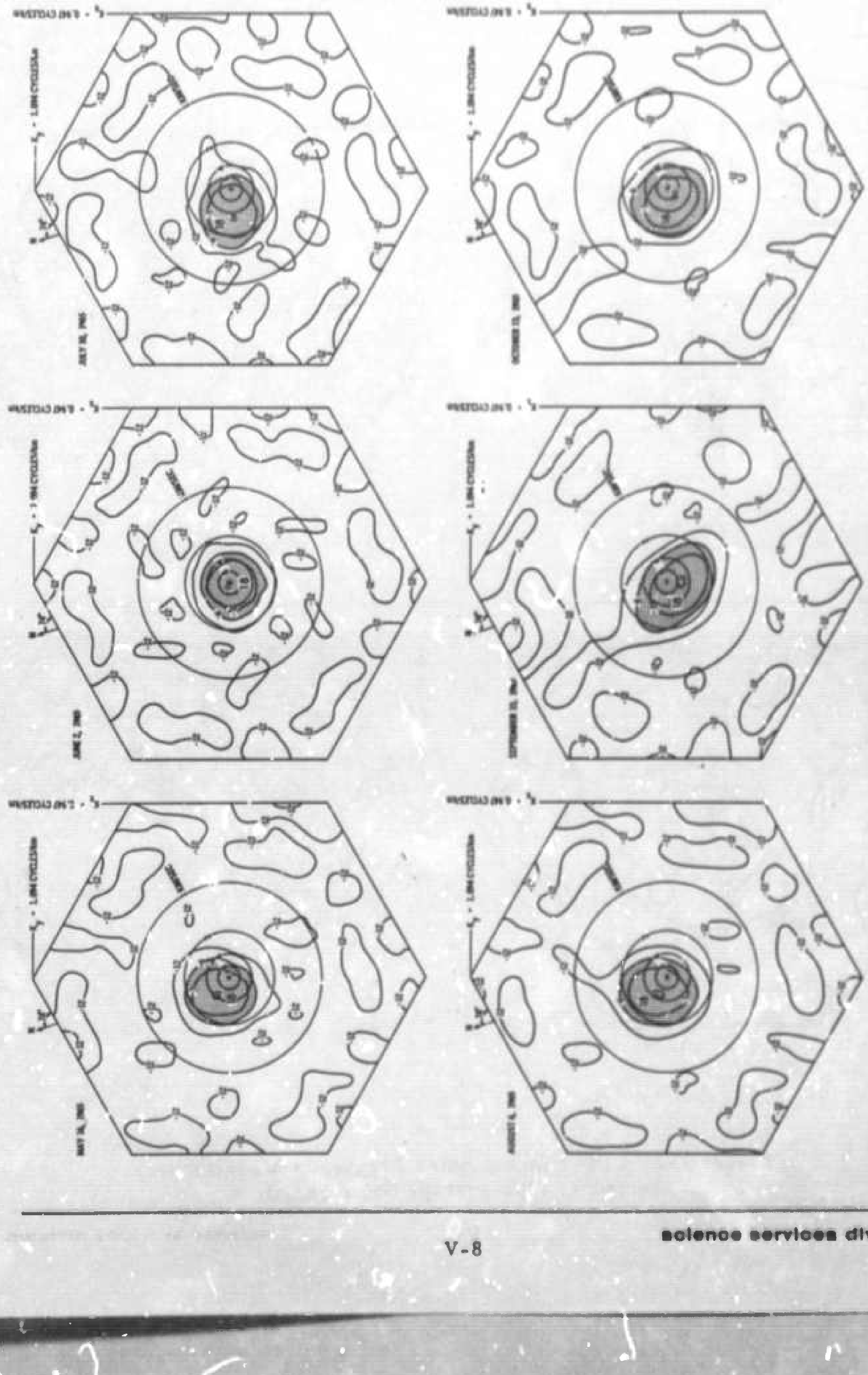


Figure V-5a. CPO Ambient Noise Frequency-Wavenumber Spectrum, May 1965 to October 1966 (f=0.5 cps)

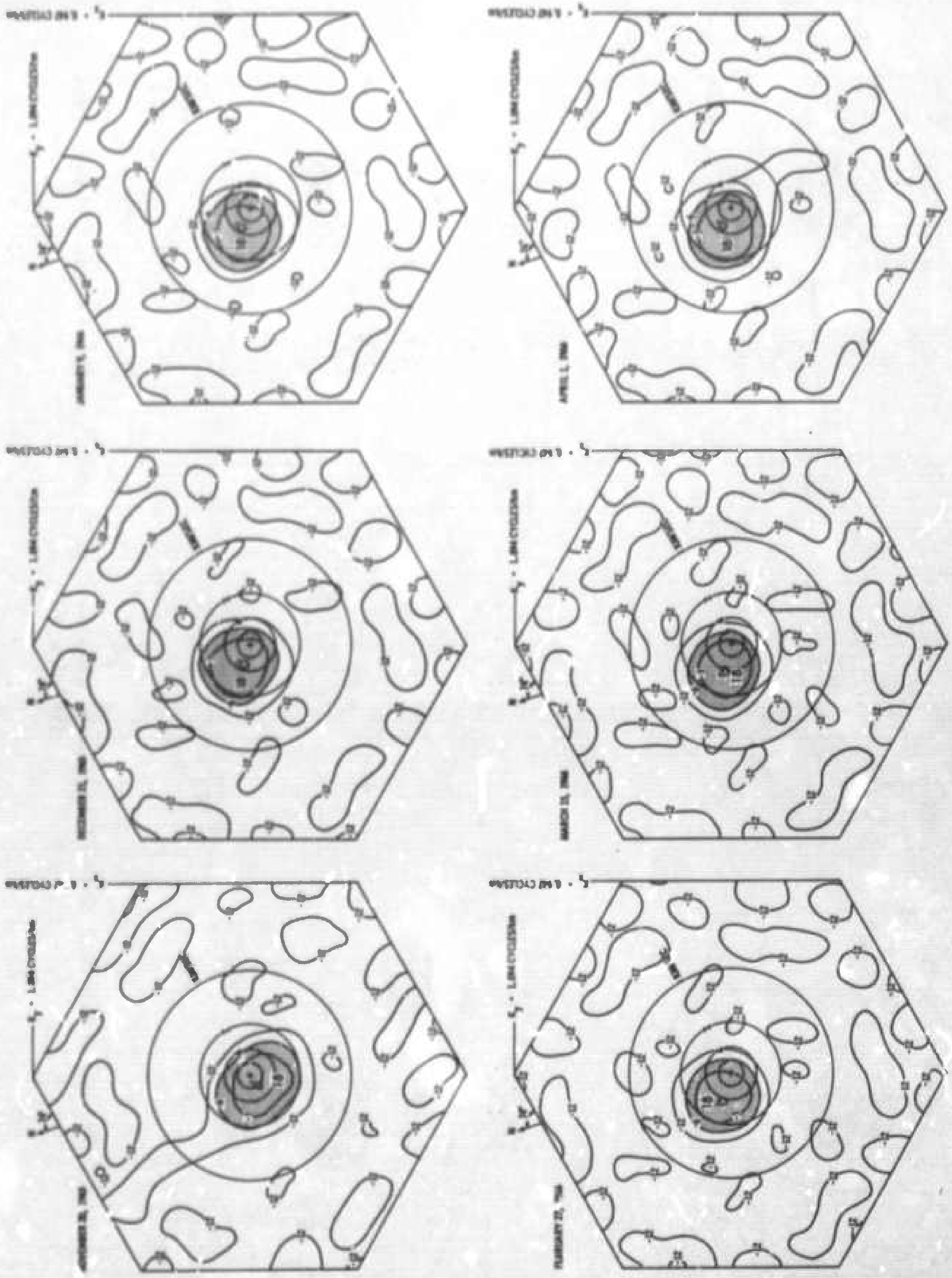


Figure V-5b. CPO Ambient Noise Frequency-Wavenumber Spectrum, May 1965 to October 1966 (f=0.5 cps)

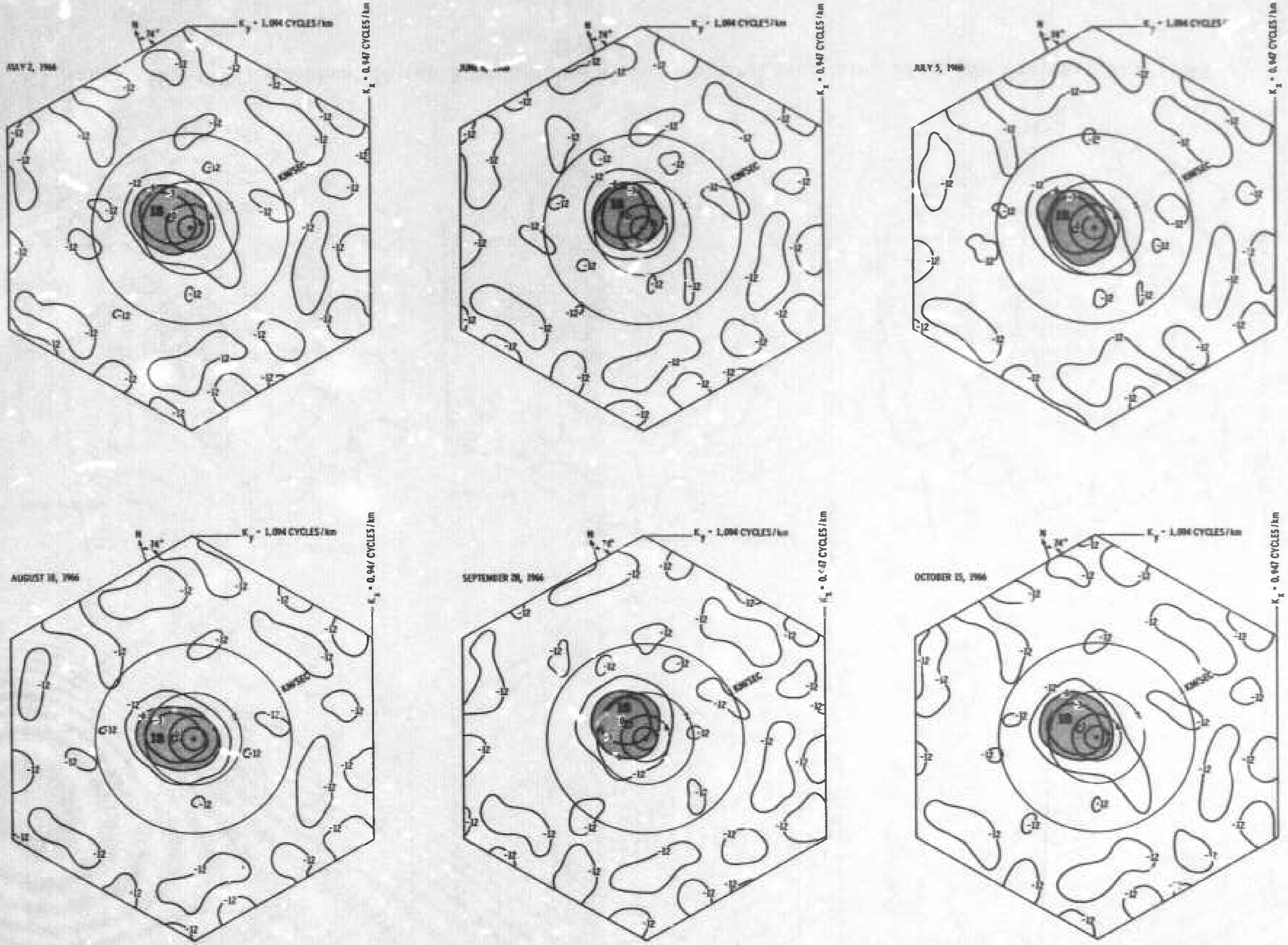


Figure V-5c. CPO Ambient Noise Frequency-Wavenumber Spectrum, May 1965 to October 1966 (f=0 5 cps)

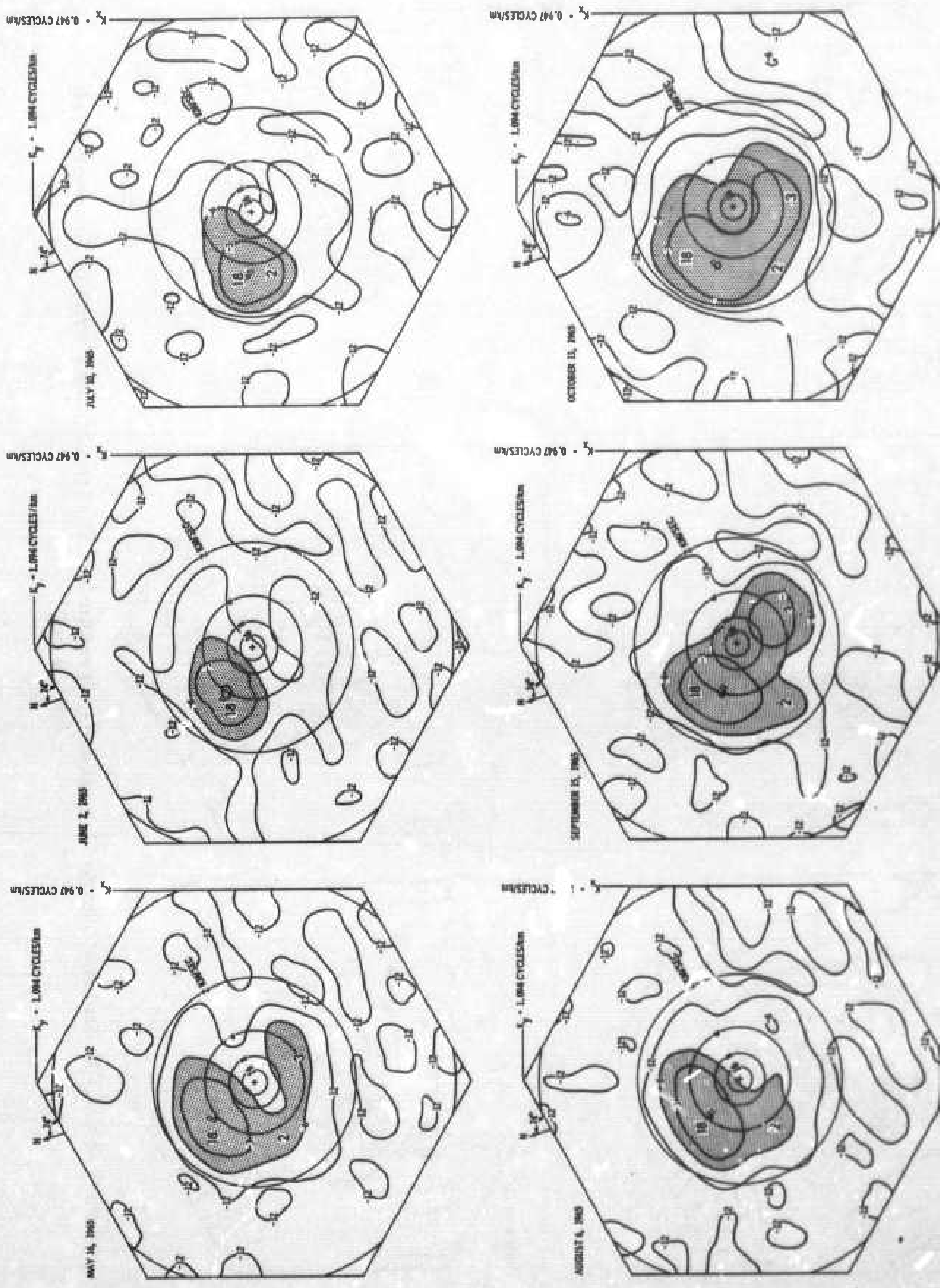


Figure V-6a. CPO Ambient Noise Frequency-Wavenumber Spectrum, May 1965 to October 1966 (f=1.0 cps)

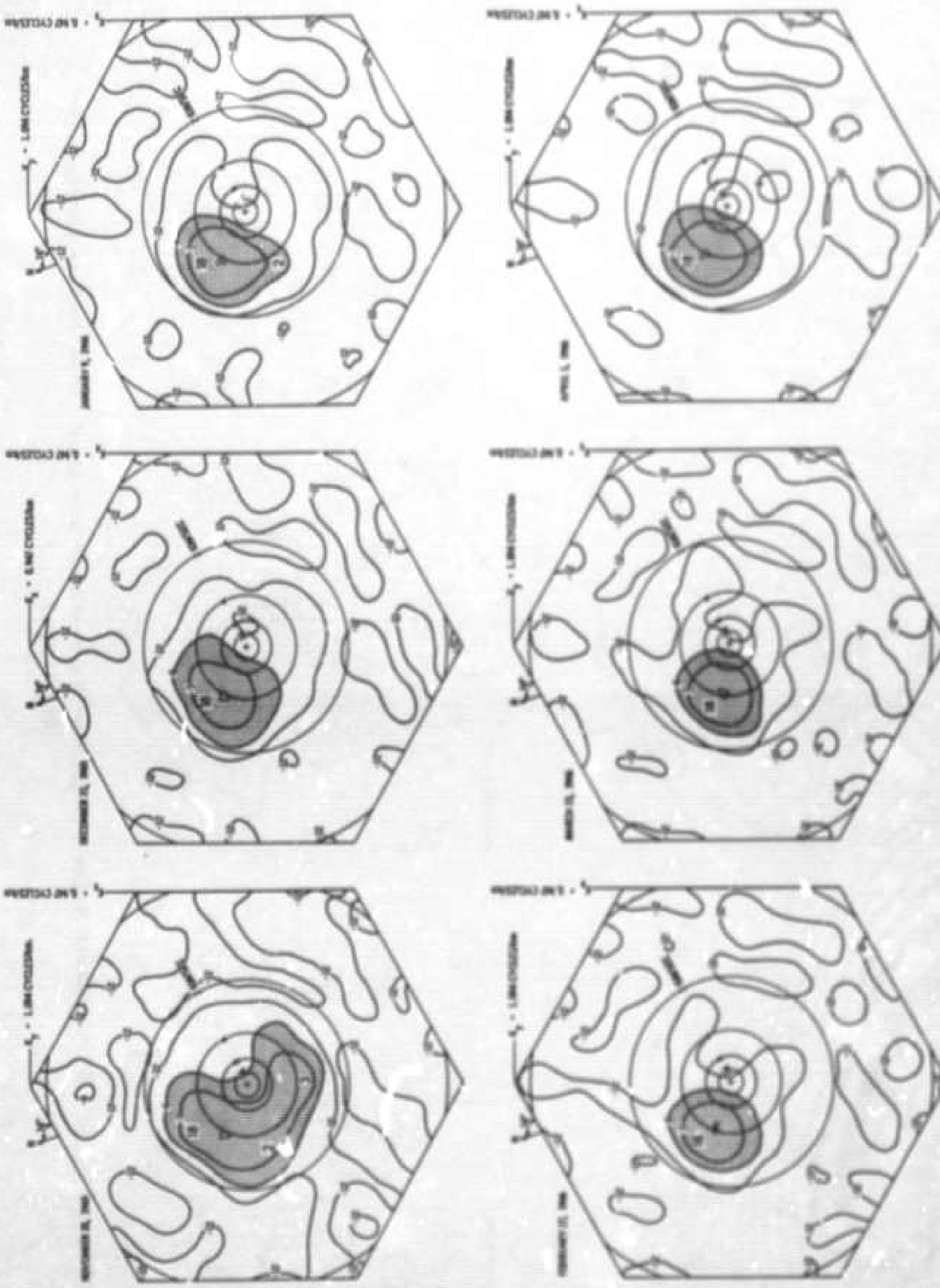


Figure V-6b. CPO Ambient Noise Frequency-Wavenumber Spectrum, May 1965 to October 1966
(f=1.0 cps)

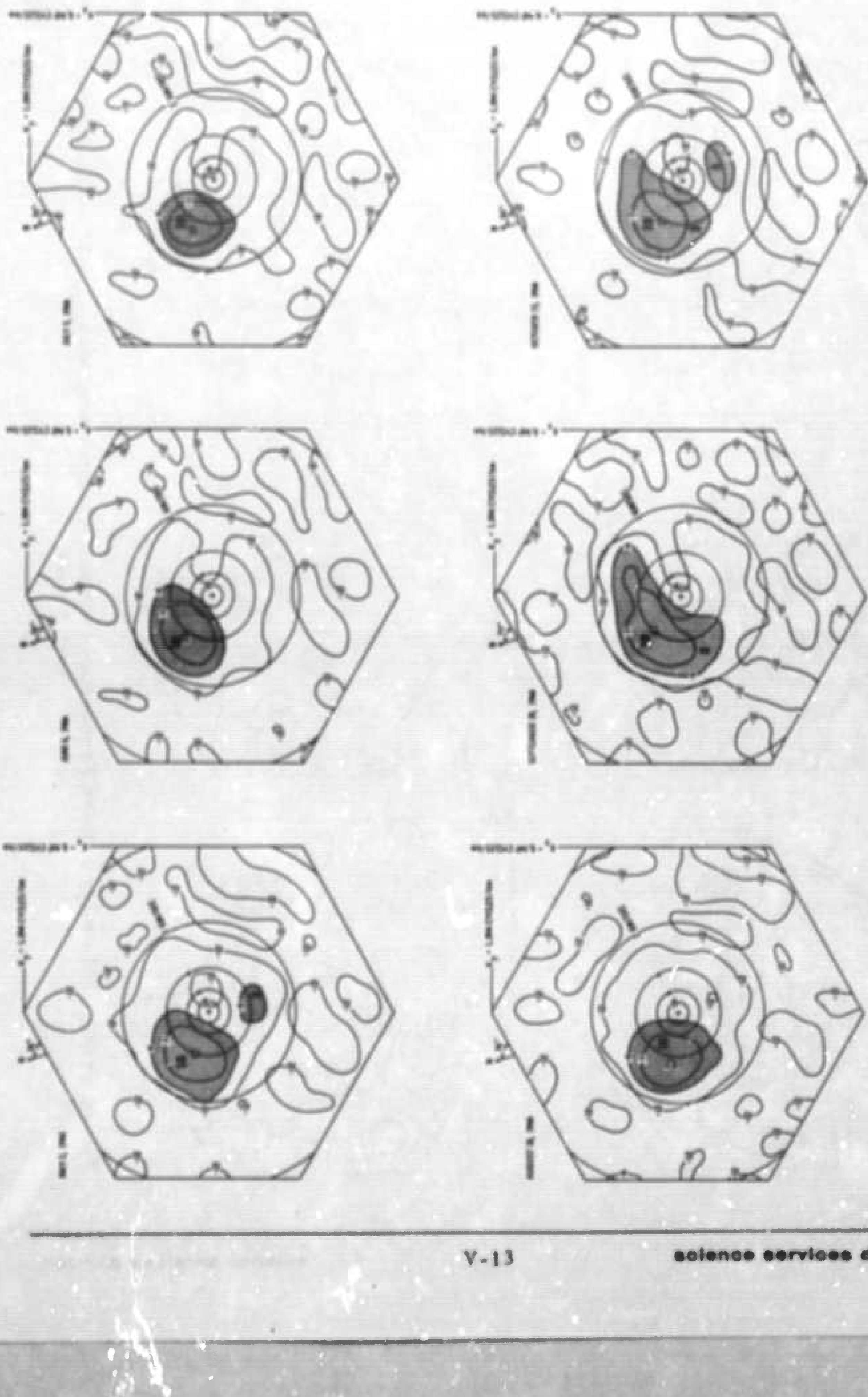


Figure V-6c. CPO Ambient Noise Frequency-Wavenumber Spectrum, May 1965 to October 1966 (f=1.0 cps)

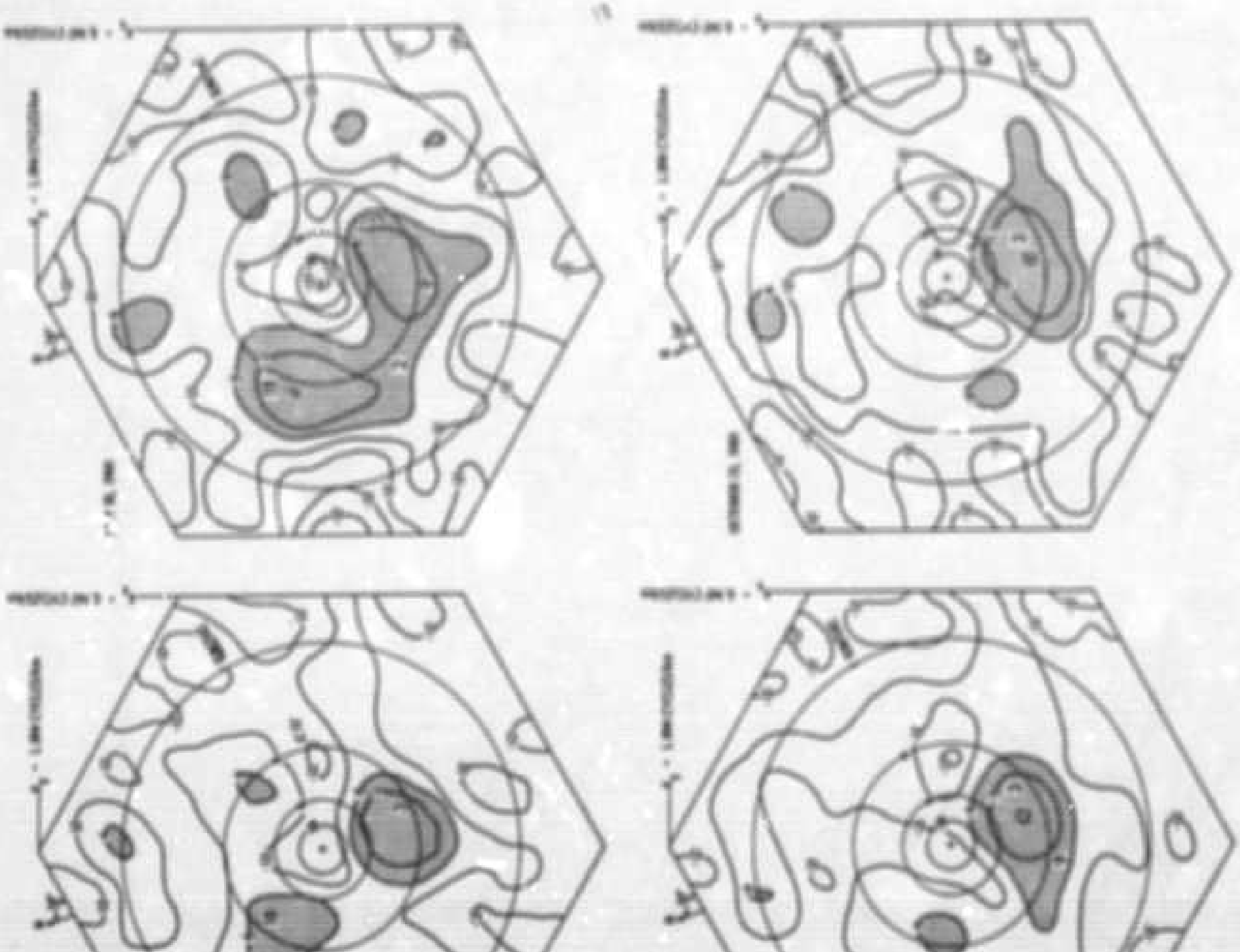


Figure V-7a. CPO Ambient Noise Frequency-Wavenumber Spectrum, May 1965 to October 1966 (f=1.5 cps)

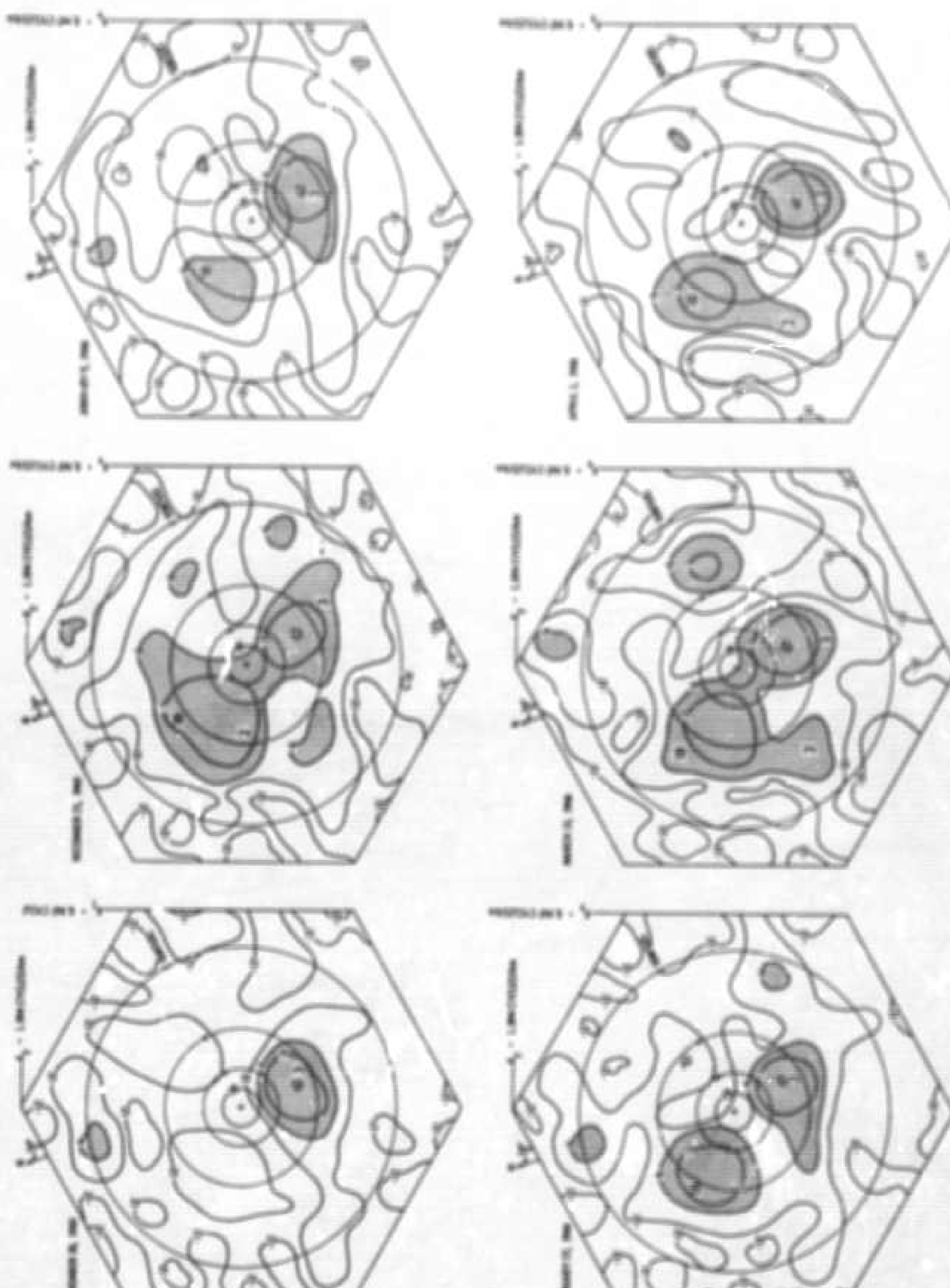


Figure V-7b. CPO Ambient Noise Frequency-Wavenumber Spectrum, May 1965 to October 1966 (f=1.5 cps)

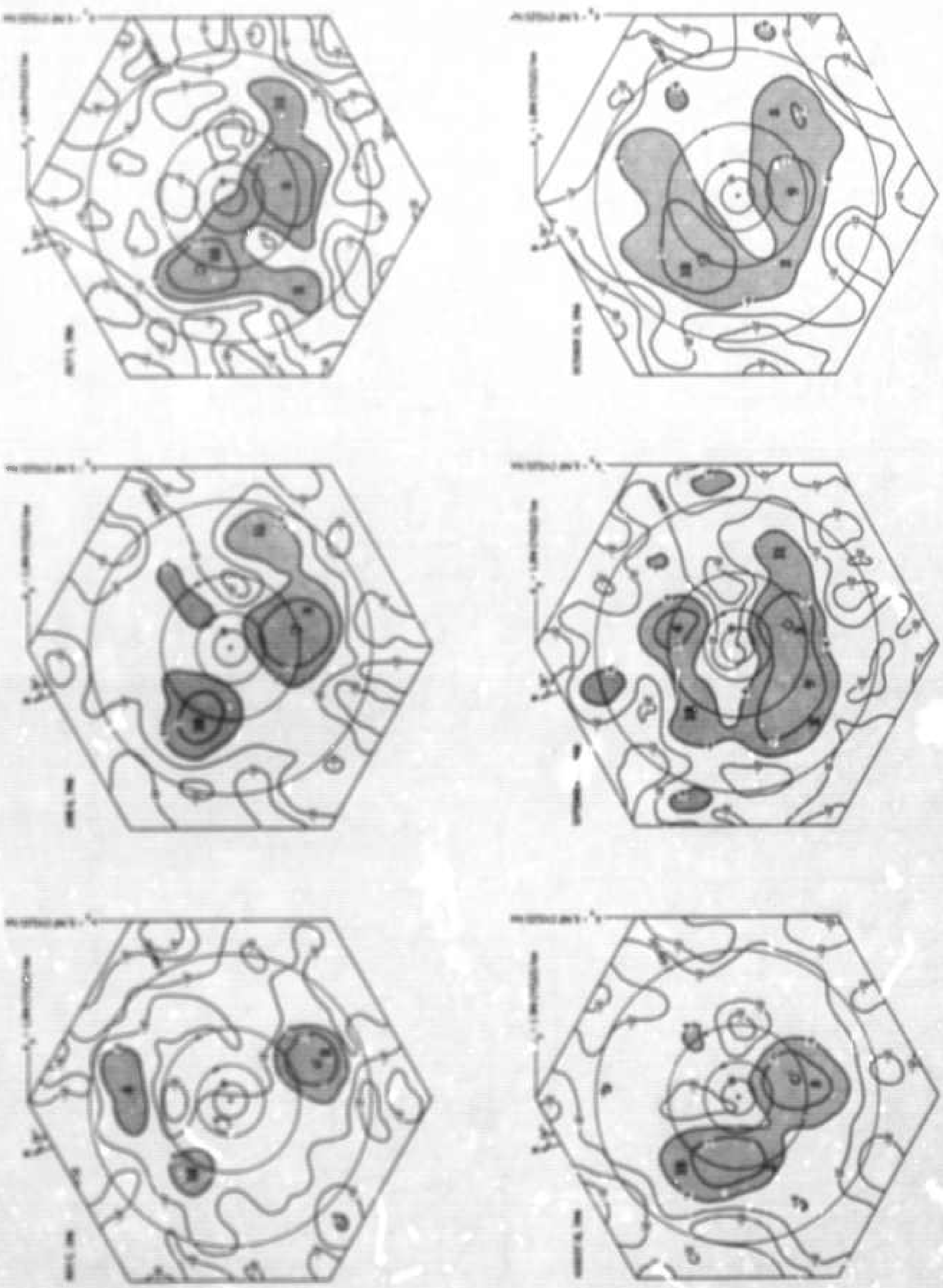


Figure V-7c. CPO Ambient Noise Frequency-Wavenumber Spectrum, May 1965 to October 1966 (f=1.5 cps)

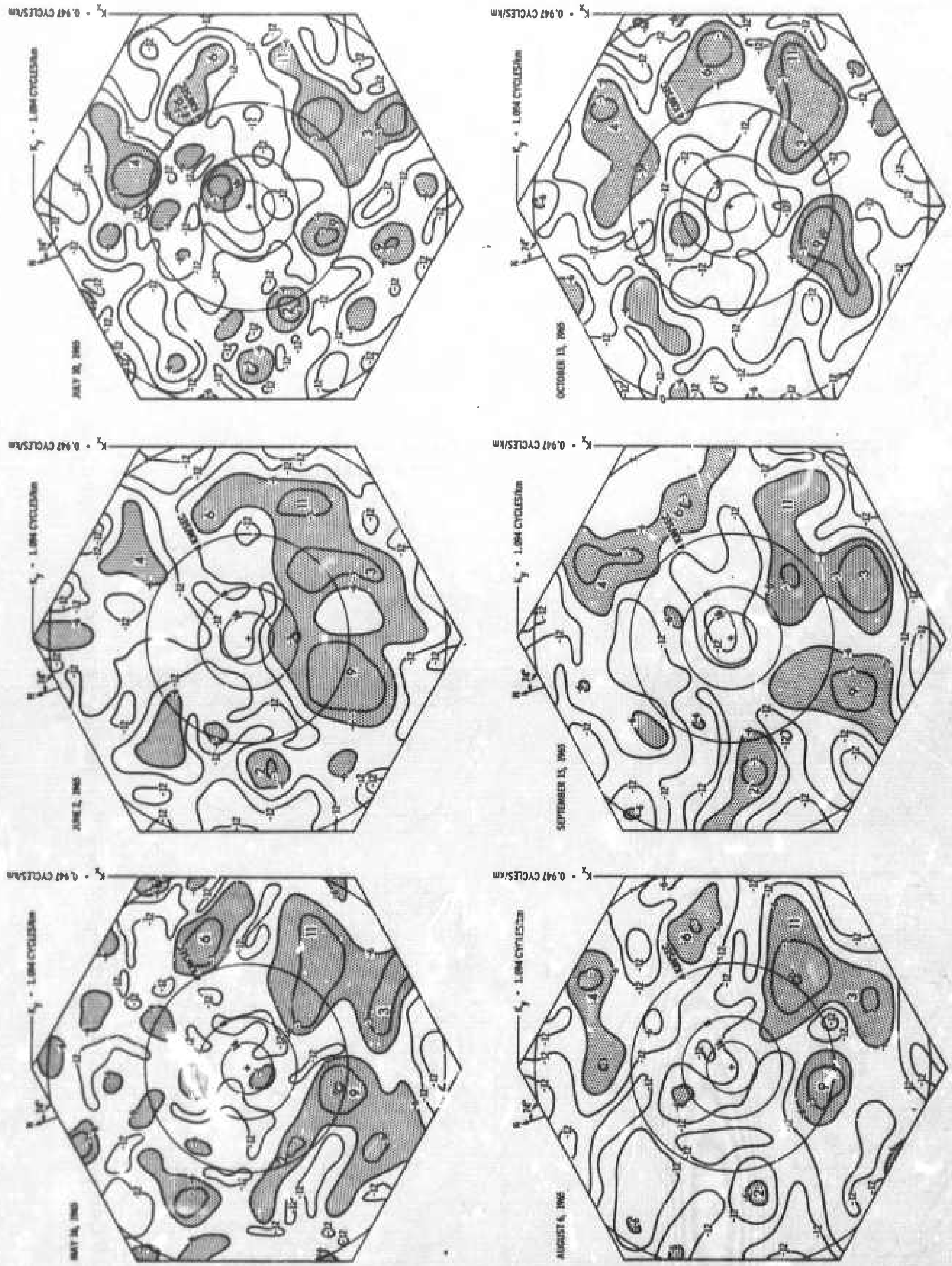


Figure V-8a. CPO Ambient Noise Frequency-Wavenumber Spectrum, May 1965 to October 1966 (f=2.0 cps)

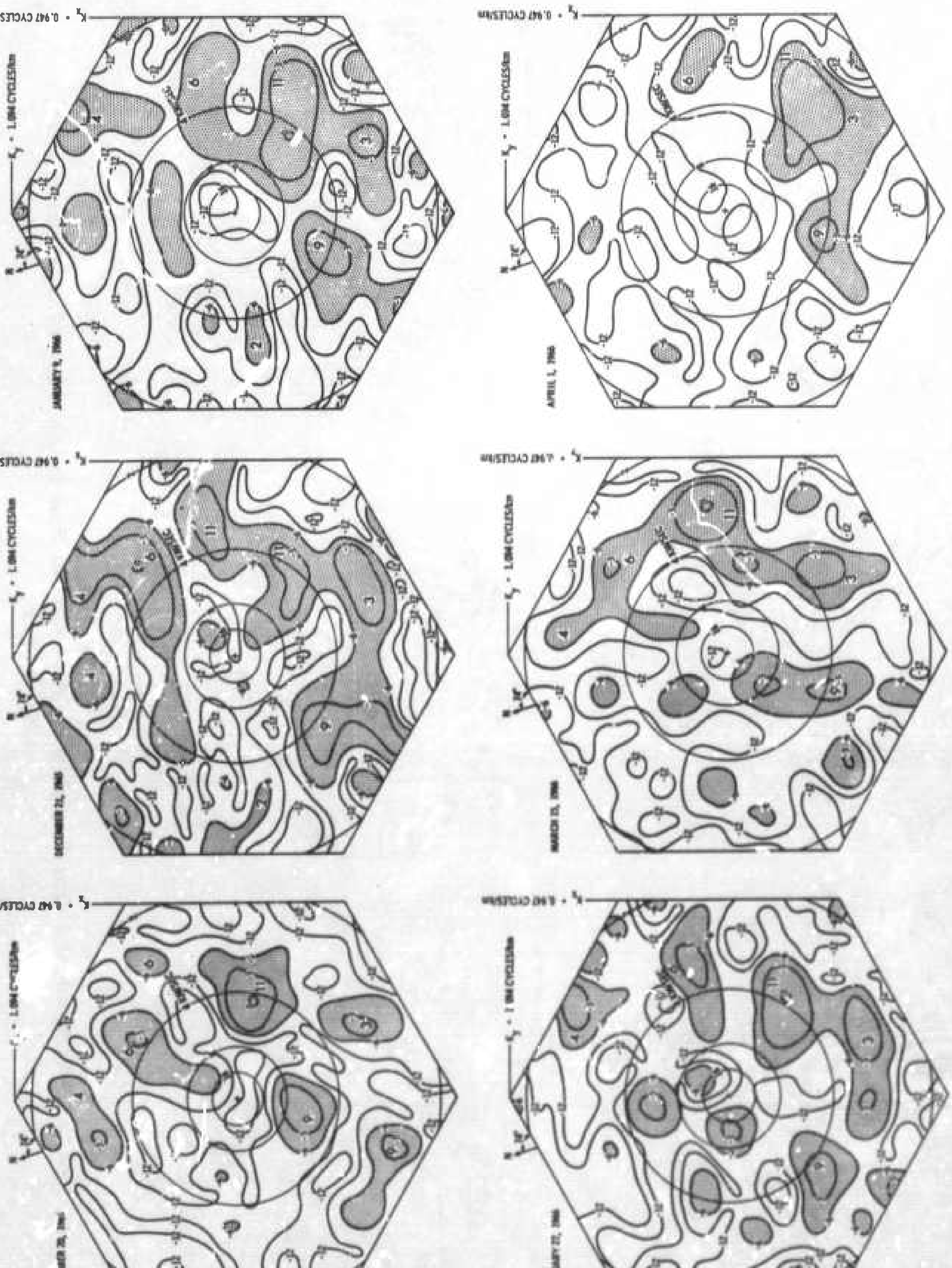


Figure V-8b. CPO Ambient Noise Frequency-Wavenumber Spectrum, May 1965 to October 1966
(f=2.0 cps)

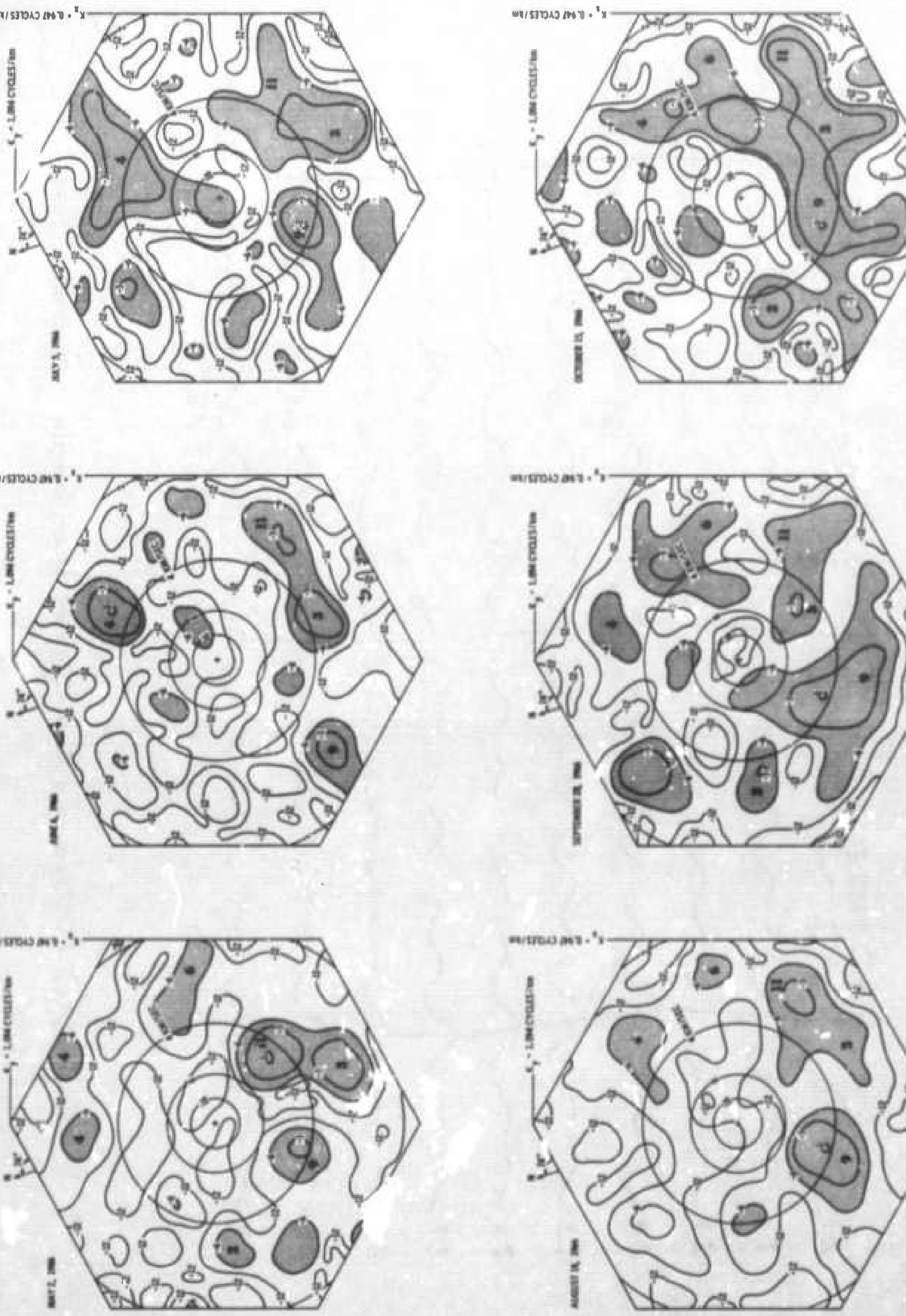


Figure V-8c. CPO Ambient Noise Frequency-Wavenumber Spectrum, May 1965 to October 1966 (f=2.0 cps)

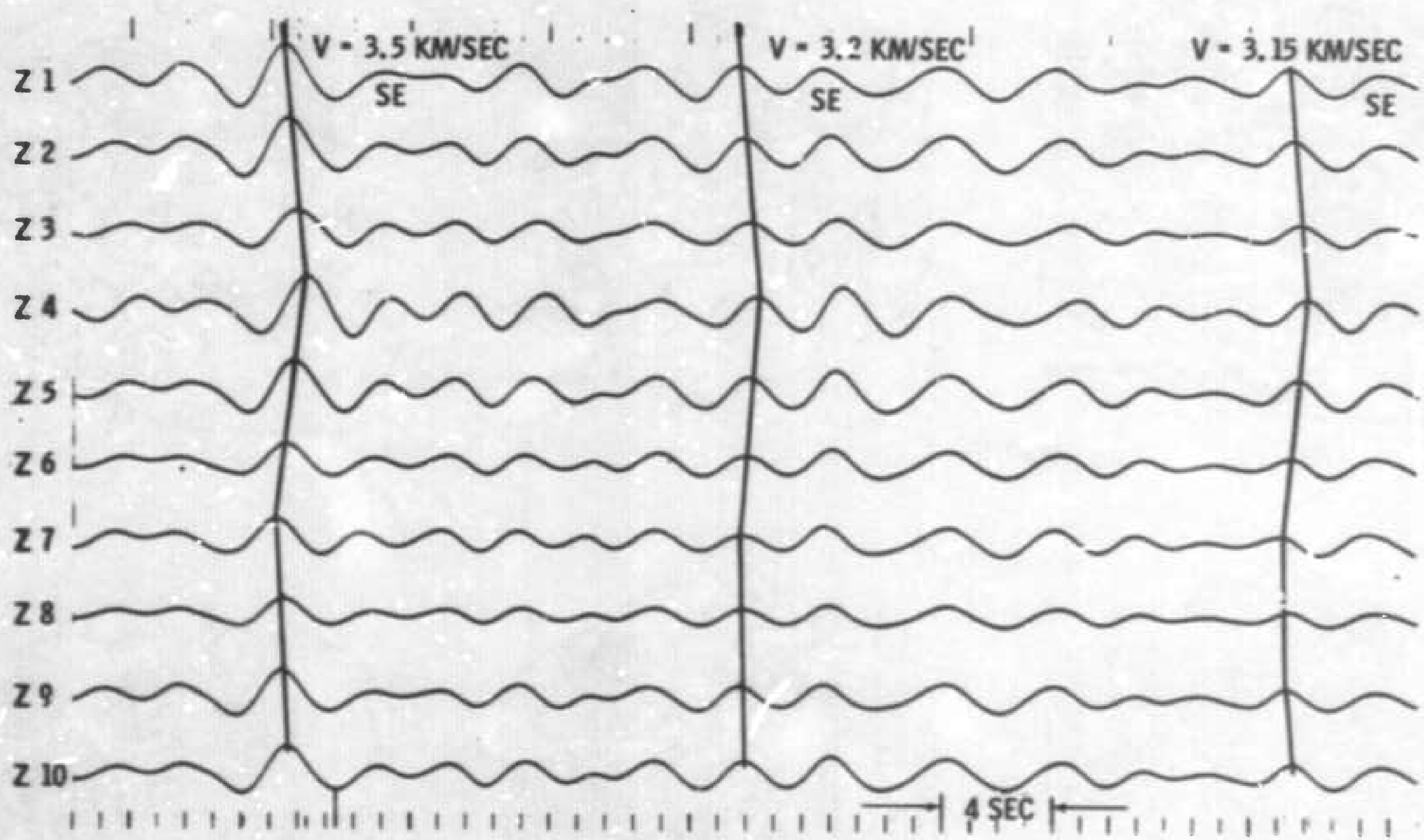


Figure V-9. CPO Frequency Band-Limited Noise Sample, 5 September 1965

with the development of low-pressure areas at sea. This increase in power can be detected at frequencies as high as 1.75 cps.

The 3-dimensional power-density spectra also show the existence of several coherent noise sources in various directions around CPO in the frequency range 1.25 to 2.25 cps which propagate across the array with an apparent horizontal velocity of approximately 3 km/sec. The predominate noise contribution comes from a N-NW direction, an area of numerous streams and dams; but a definite generating source could not be assigned to any of the coherent noise due to the lack of information concerning possible generating sources in the various directions around CPO. The various coherent noise sources seem to remain time-stationary except for slight power fluctuations.

Prediction-filtering results indicate that the percentage of spatially coherent noise changes significantly with the occurrence of tropical storms and low-pressure areas off the coastline, indicating an increase in the spatially organized noise for all frequencies below 1.75 cps. This increase in the spatially organized noise for all frequencies below 1.75 cps. This increase is comparable to an equivalent power increase in the single-channel power-density spectra during the same time period.

3. High-Velocity 3-dimensional Noise Power-Density Spectra

A study investigating ambient-noise properties in the signal-velocity regions of wavenumber space was conducted using high-resolution wavenumber spectra techniques. A strong coherent noise lobe in the signal-velocity region decreases the S/N ratio for signals from that direction.

In the velocity region of interest (velocities greater than or equal to 8.1 km/sec), the mantle P-wave energy is a strong contributor of power to the spatially coherent ambient-noise field in the frequency band of

interest. Figures V-10 through V-12 were calculated for various directions and velocities of the signal region. In each case, the distributions approach the estimated mantle P-wave noise level.

The 1.0-cps energy is particularly interesting, since it was found to be highly directional. Predominant 1.0-cps energy could be detected from the south or Gulf Coast area for all velocities studied. Also, significant 1.0-cps energy from S60°W exists with a velocity greater than or equal to 1.26 km/sec.

At 1.25 cps, the most significant noise energy appears to arrive from the direction of the Great Lakes region with velocities of approximately 8.1 km/sec. Directional properties for the P-wave contribution at other frequencies appear to be random for the higher velocities.

4. Implication on MCF On-Line Processing

Results of this noise study indicate that on-line multichannel processing can be effectively conducted at CPO. Furthermore, they indicate that a multichannel filter (MCF) designed from ensemble or average noise can be effectively used over extended periods of time. However, during periods of low pressure or storms at sea, greater efficiency may be acquired by using a filter designed from corresponding data.

The high-resolution power spectra over the high-velocity noise regions presented results which exhibit a possible interference with certain incoming signals. This noise energy propagates from the south or Gulf Coast region and, therefore, during the mentioned disturbances at sea, could reduce signals from this direction with the same apparent P-wave velocity.

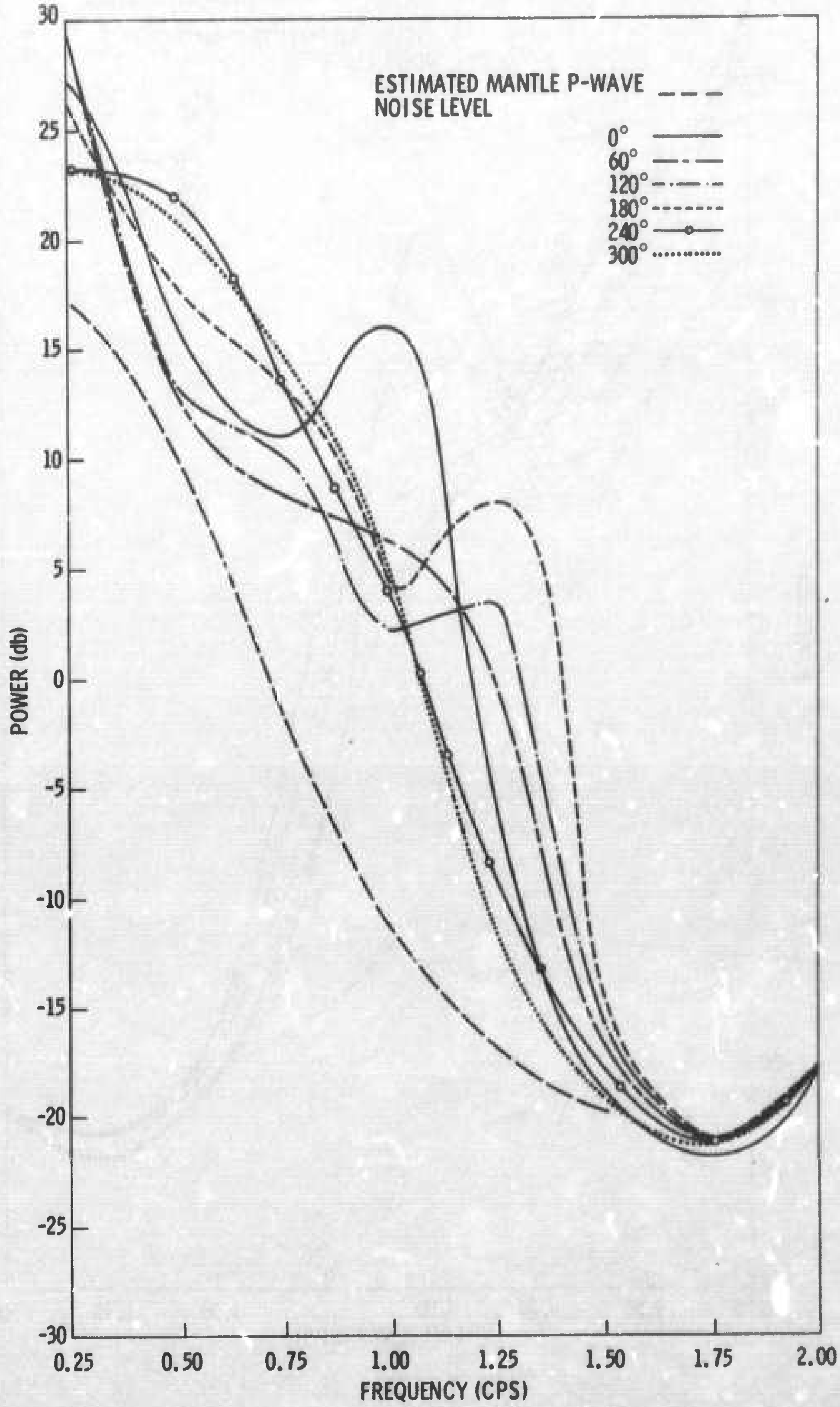


Figure V-10. Directional Power Distribution of CPO P-Wave Energy at 8.1 km/sec

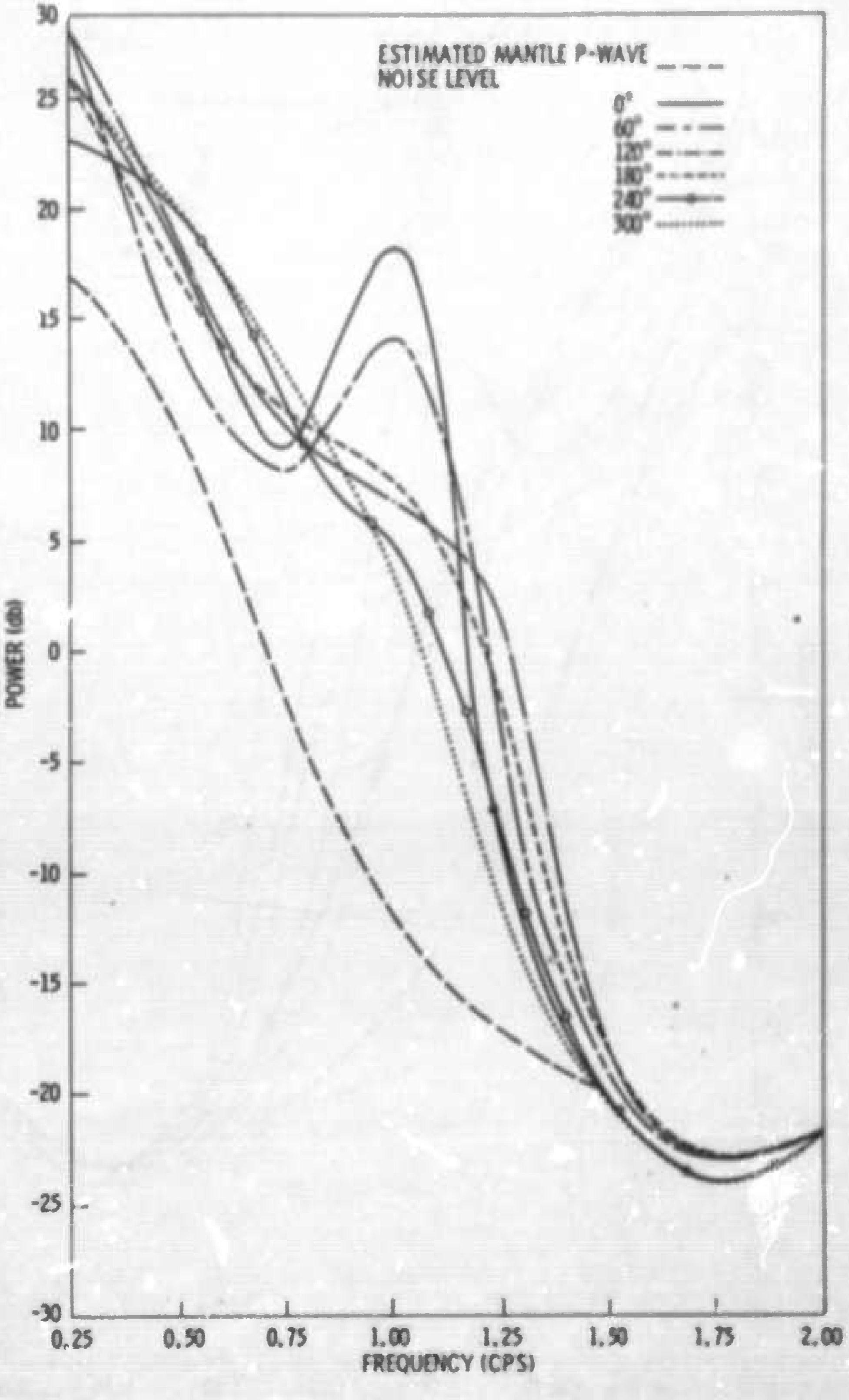


Figure V-11. Directional Power Distribution of CPO P-Wave Energy at 12.6 km/sec

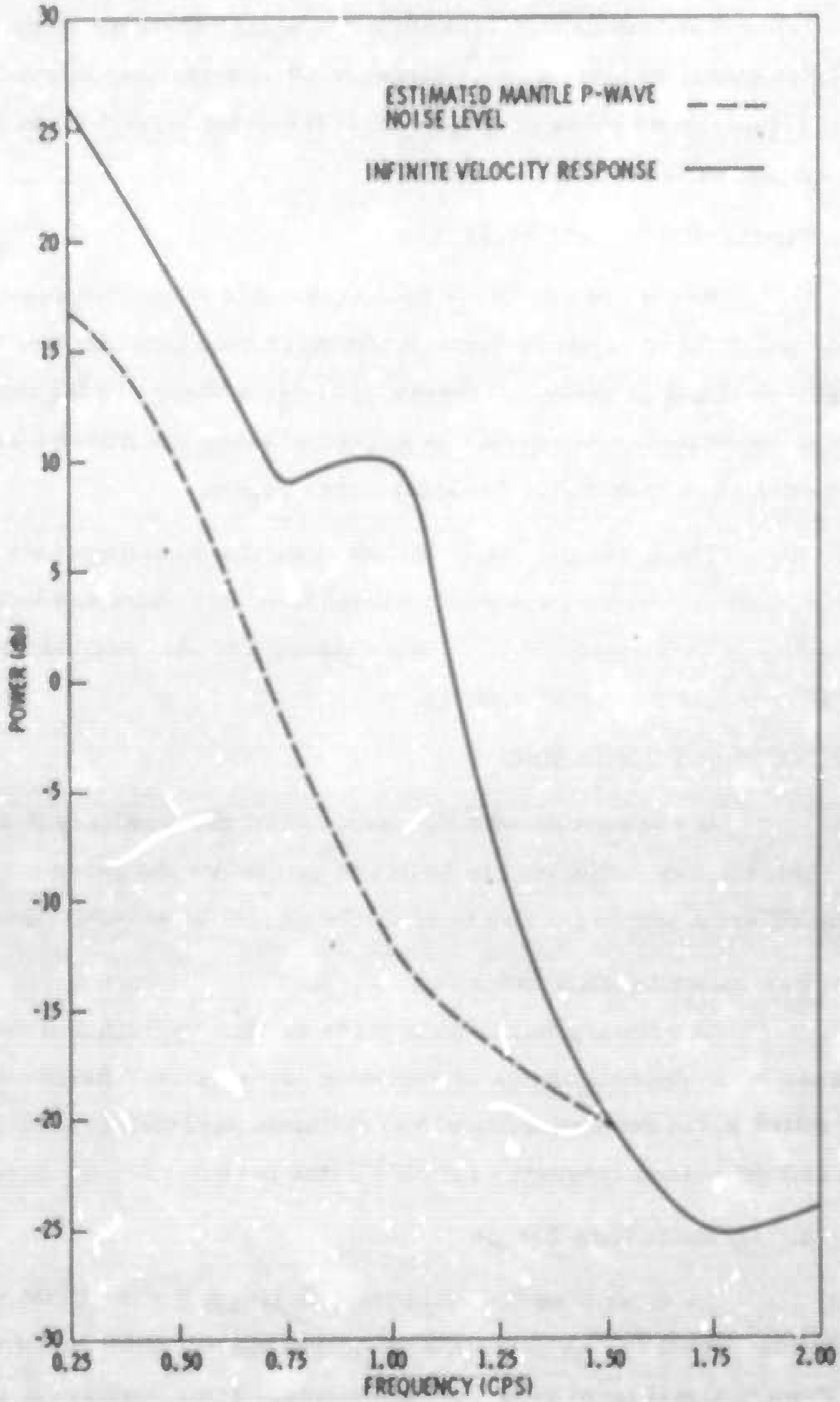


Figure V-12. Power Distribution of CPO P-Wave Energy at Infinite Velocity

This result is discussed in the signal-to-noise study presented in the CPO Annual Report No. 1.[5] However, it is important to note that the low- and high-velocity noise propagate from the same direction and probably can be attributed to the same source.

5. Summary and Conclusions

Results of this study have shown that the ambient-noise field at CPO has not changed significantly over extended time periods, nor has it changed on a daily or seasonal basis. However, there is a change in the noise field which can be related to microseisms generated along the Atlantic and Gulf Coast regions and, possibly, the Great Lakes region.

These results imply that an accurate modeling of the CPO noise field can be used to generate a multichannel filter set which can be used in a DMCF processor to reject ambient noise throughout the year, except for periods of intense microseismic activity.

B. DETECTION PROCESSING

In conjunction with the operation of the Auxiliary Processor at CPO, research was performed in Dallas to determine the parameters to be used with the different processes and to study the effects of varying these parameters.

1. Parameter Specifications

Of primary importance in the on-line operation of the Auxiliary Processor is the correct choice of operating parameters. Research in Dallas has resulted in the determination of two optimum parameters -the signal gate length and the corner frequency for MCF0 (the prefilter for the Fisher process).

a. Optimum Gate Length

To determine the optimum gate length for the Fisher and Wiener computations, a study was performed to determine the time duration of the primary P-wave signal from recorded teleseisms. Time duration is important because the processes are optimized when their computation gate length equals

the signal duration. A visual analysis of 57 teleseisms showed a P-pulse mean signal duration of 2.90 sec and a variation in P-pulse signal duration of 1.90 sec. As a result of this study, the gate length was changed to 3.0 sec. After this adjustment, analysts reported data easier to analyze, since the processed traces (notably the Fisher) were stabilized, and did not correlate as well in time.

b. Optimum Low-Cut Filter

Several low-cut filters with varying corner frequencies were developed to determine the optimum low-cut filter to be used in the MCF0 subsection of the processor. The choice of this filter is extremely important since it is the prefilter for the Fisher subroutine, and filtering of the input data to the Fisher process is necessary in order to remove highly-correlated low-frequency microseismic energy.

The filters with 0.75-, 1.0- and 1.25-cps corner frequencies were applied off-line to a CPO theoretical noise sample[2] and the Fisher output computed for each of the three cases. Results of this processing (shown as a cumulative distribution) are given in Figure V-13. Figure V-13 shows that the optimum low-cut prefilter should have a corner frequency of 0.75 to 1.00 cps.*

Greater suppression of coherent noise could be obtained by choosing a filter with a corner frequency higher than 0.75 cps, but this would cause extensive signal degradation since the predominate portion of the P-wave usually occurs between 0.6 and 1.0 cps.

The average signal spectrum was investigated to determine the optimum trade-off between minimizing the Fisher noise distribution (low-cut

*When interpreting Figure V-13 and the other cumulative distributions presented in this report, the horizontal scales are not linear. Even though the curves may appear very similar, their true meaning can be interpreted by noting the last several inches on the horizontal scale.

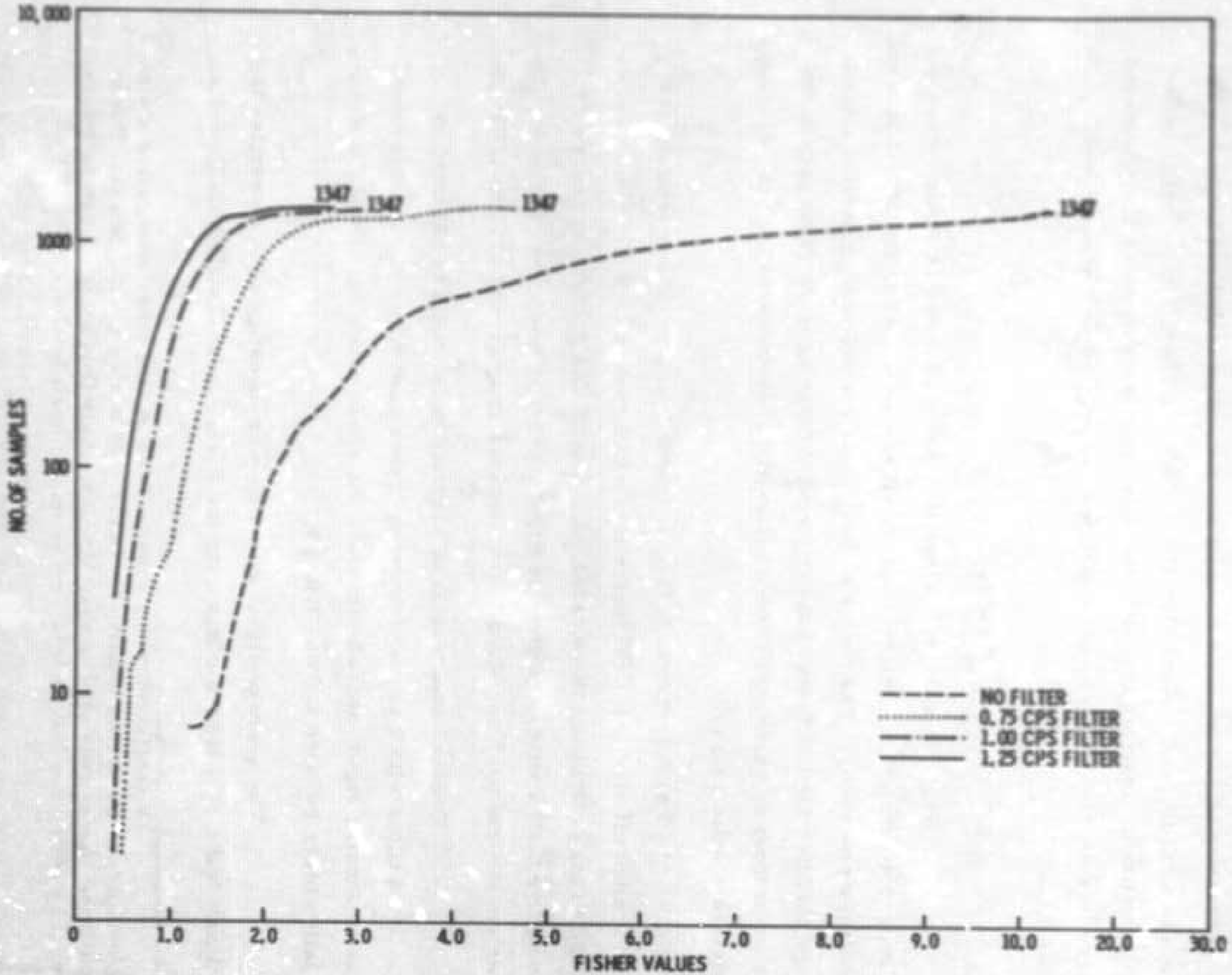


Figure V-13. Cumulative Distribution for Fisher Statistics for Theoretical Noise Sample Using No Filter, 0.75-, 1.0-, and 1.25-cps Low-Cut Filters

frequency filtering) and maintaining adequate signal energy. The average CPO signal spectrum was computed for an ensemble of Kurile Islands' events developed under Contract AF 33(657)-12747 and is shown in Figure V-14. Peak signal energy occurs at 0.68 cps. Since this result could be tuned to the Kurile Islands region and not represent an average of the CPO predominant P-wave energy, additional P-wave data were derived from the CPO standard analysis forms. An average predominate P-wave frequency of 0.82 cps was determined from one month of standard station report data.

Based on the Fisher noise output distribution and with the knowledge that the peak signal spectrum lies between 0.68 and 0.82 cps, the 0.75-cps low-cut filter was chosen for on-line application.

2. Fisher Noise Properties

a. Threshold Non-Time Stationarity

The Fisher output noise distribution non-time stationarity was studied. Four noise samples, I, II, III, and IV, were chosen for processing from the 1965 CPO library (Figure V-15) and represent the different types of noise backgrounds encountered at CPO (low—I, medium—II and III, and high—IV). The Fisher statistic for the four samples is shown in Figure V-16. These illustrations show the Fisher statistic to be larger for high noise (sample IV) and smaller for the other samples.

Although sample I is of low-level noise, its Fisher statistic is larger than those from samples II and III. While the cause for this is unknown, it is possible that the mantle P-wave noise level was much higher for sample I than for samples II and III, causing this result.

Figure V-16 shows that the large majority of Fisher values (the 50-percent level) occur at approximately F=2.0. This value closely agrees with that published in earlier work on the Fisher statistic. The real significance of this data is that the cumulative distribution in Figure V-16 shows that

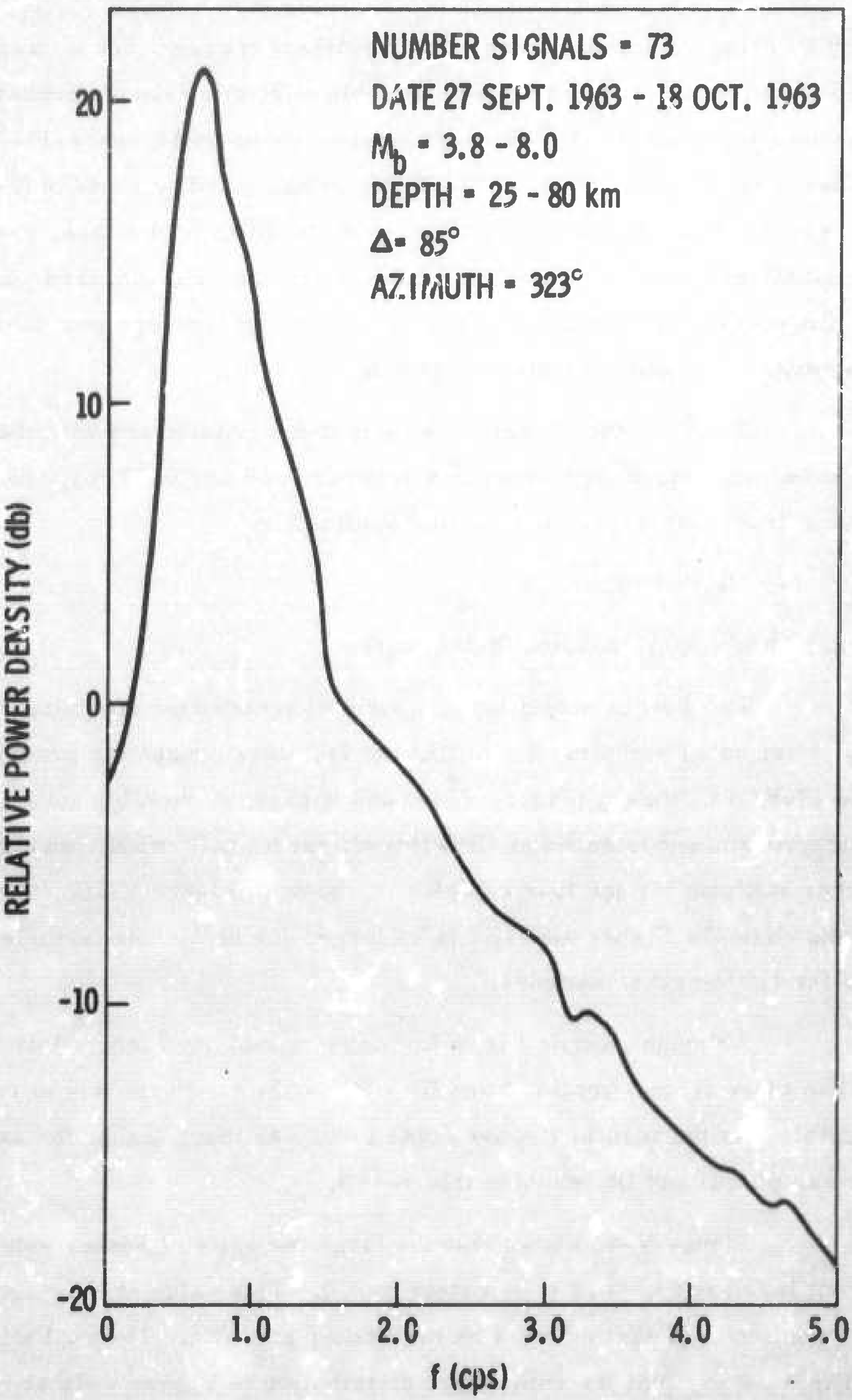


Figure V-14. CPO Average Signal Spectrum

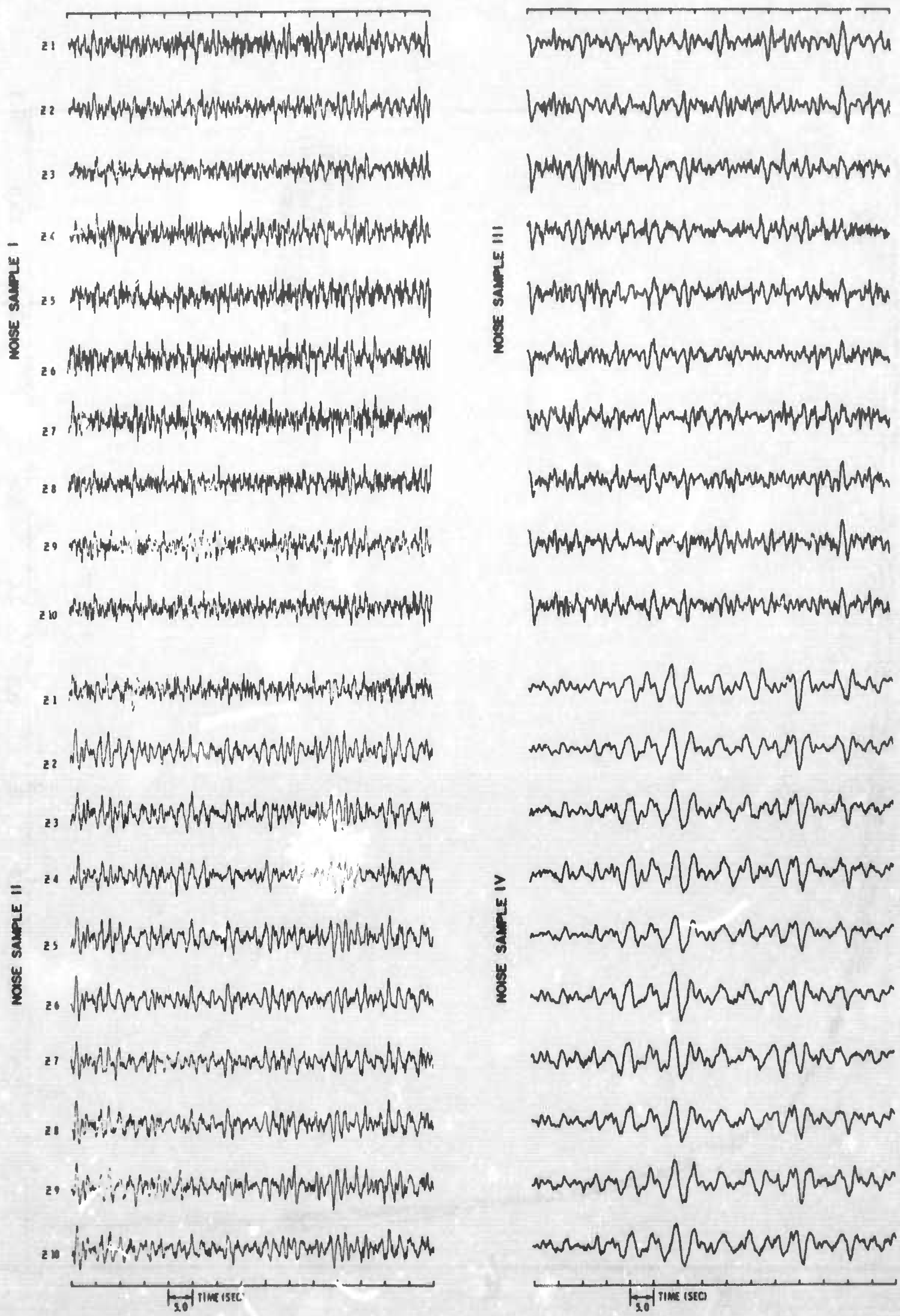


Figure V-15. Noise Samples I, II, III, and IV from 1965 CPO Noise Library

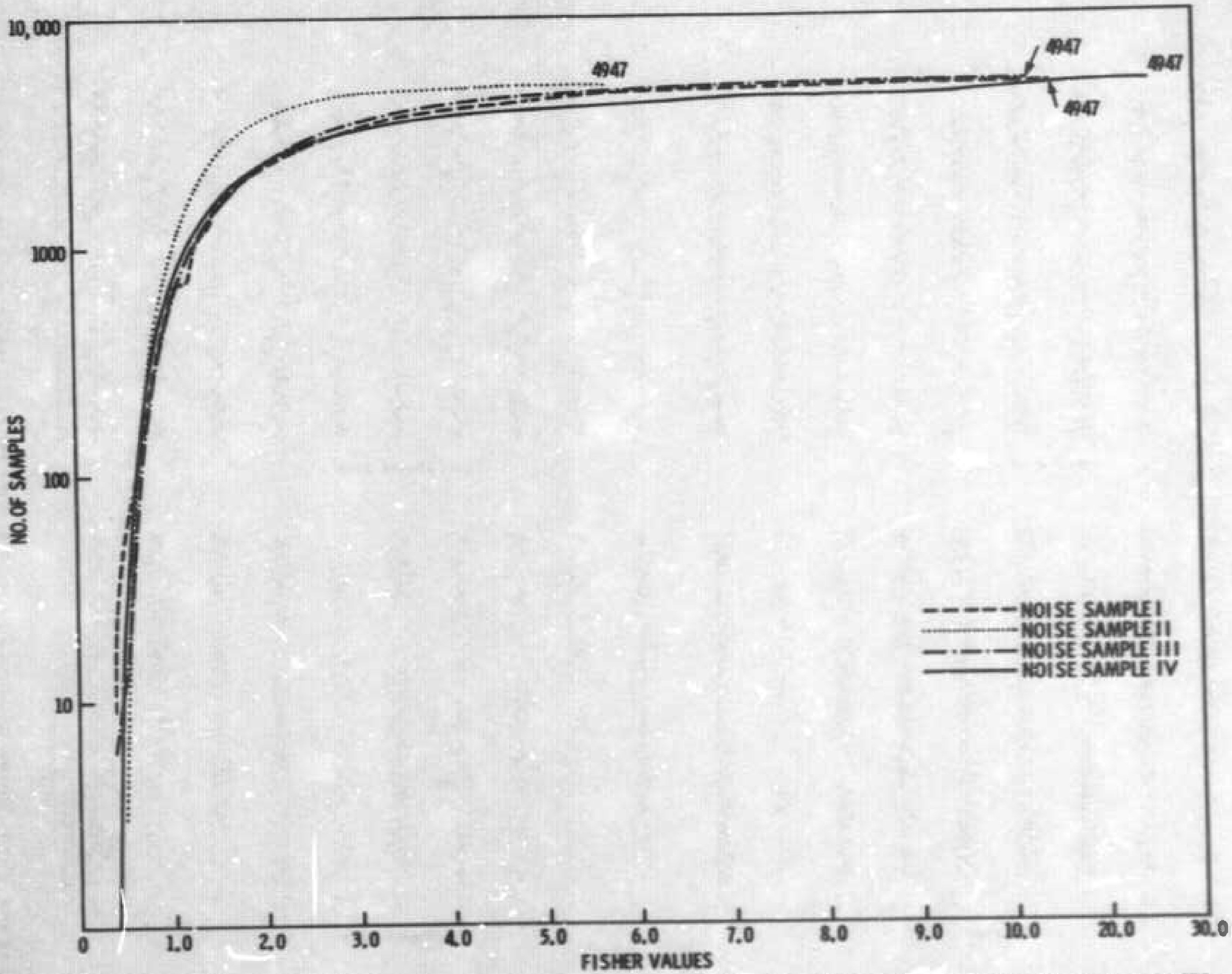


Figure V-16. Cumulative Distribution for Fisher Statistics for Noise Samples I, II, III, and IV

the threshold level for fixed false-alarm rate is variable and not strongly related to the power density spectrum of the ambient noise.

b. Effect of Correlated Noise on the Fisher Statistic

To study the effect of correlated noise on the Fisher Statistic (which assumes a spatially random noise distribution), a sample recorded in 1963 was processed. The noise sample is shown in Figure V-17 and the cumulative distribution of its Fisher statistic using no filter and for corner frequencies of 0.75, 1.0 and 1.2 cps is plotted in Figure V-18. Results are similar to those presented in Figure V-13 and indicate that the correlated noise strongly effects the Fisher output statistic below 1.0 cps.

Attempts to correlate the distribution changes to noise predictability were unsuccessful. Present estimates of the mantle P-wave noise spectrum indicate that this energy is predominate at lower frequencies and rapidly decays up to 1.0 to 1.4 cps which could significantly affect the Fisher and Weiner outputs below 1.0 cps.

3. Fisher Signal Properties

A set of theoretical white signal wavelets was generated to determine the relation between Fisher output value and signal velocity. These wavelets were generated for infinite apparent horizontal velocity and apparent horizontal velocities of 25, 12 and 8 km/sec. Azimuthal directions were chosen so that the signals would be incident to the array at points of maximum (180°) and minimum (270°) values of the array response. The wavelets were synthetically added to the theoretical noise sample and the Fisher statistic computed. Figure V-19 is an example of the noise plus wavelet for the infinite velocity case. The cumulative Fisher distributions are shown in Figure V-20. From Figure V-20 two conclusions are drawn:

- For a given velocity, the direction has very little effect on the Fisher values. This result is expected due to the near symmetry of the CPO array.

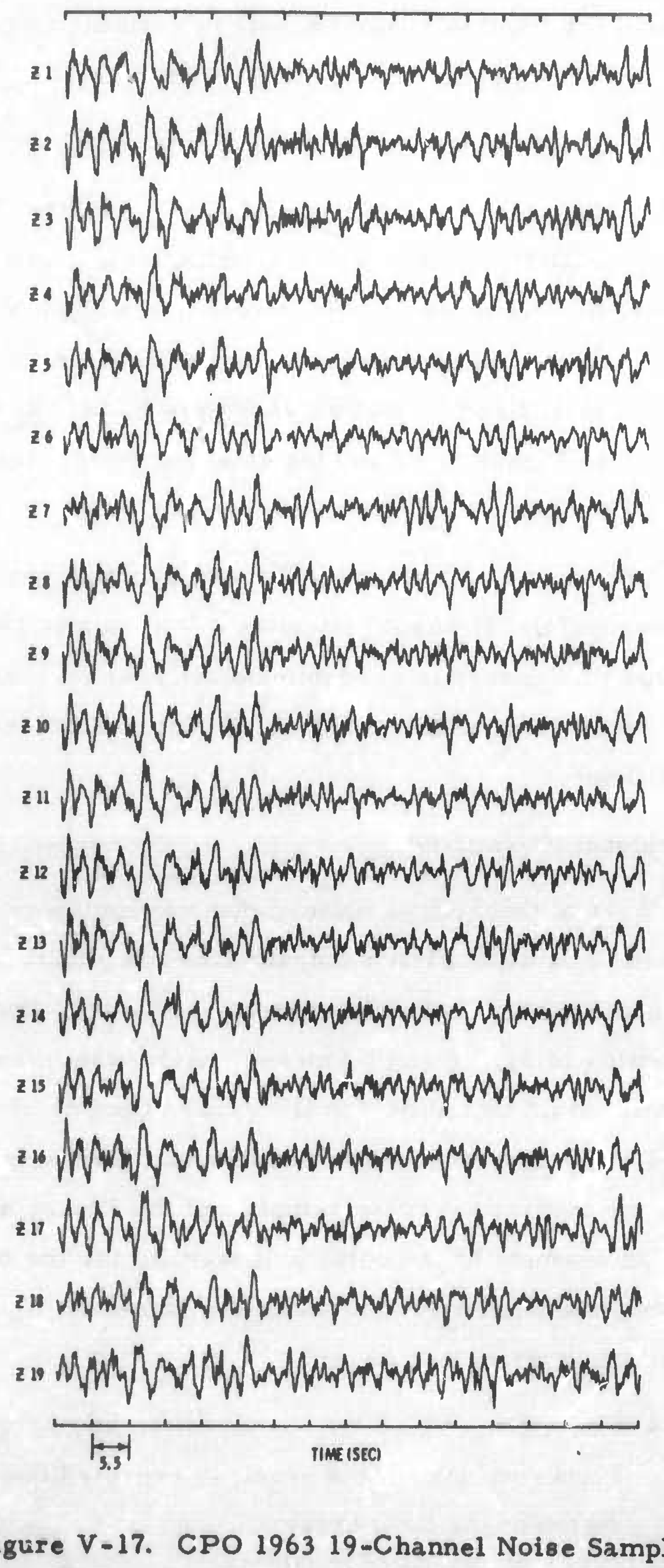


Figure V-17. CPO 1963 19-Channel Noise Sample

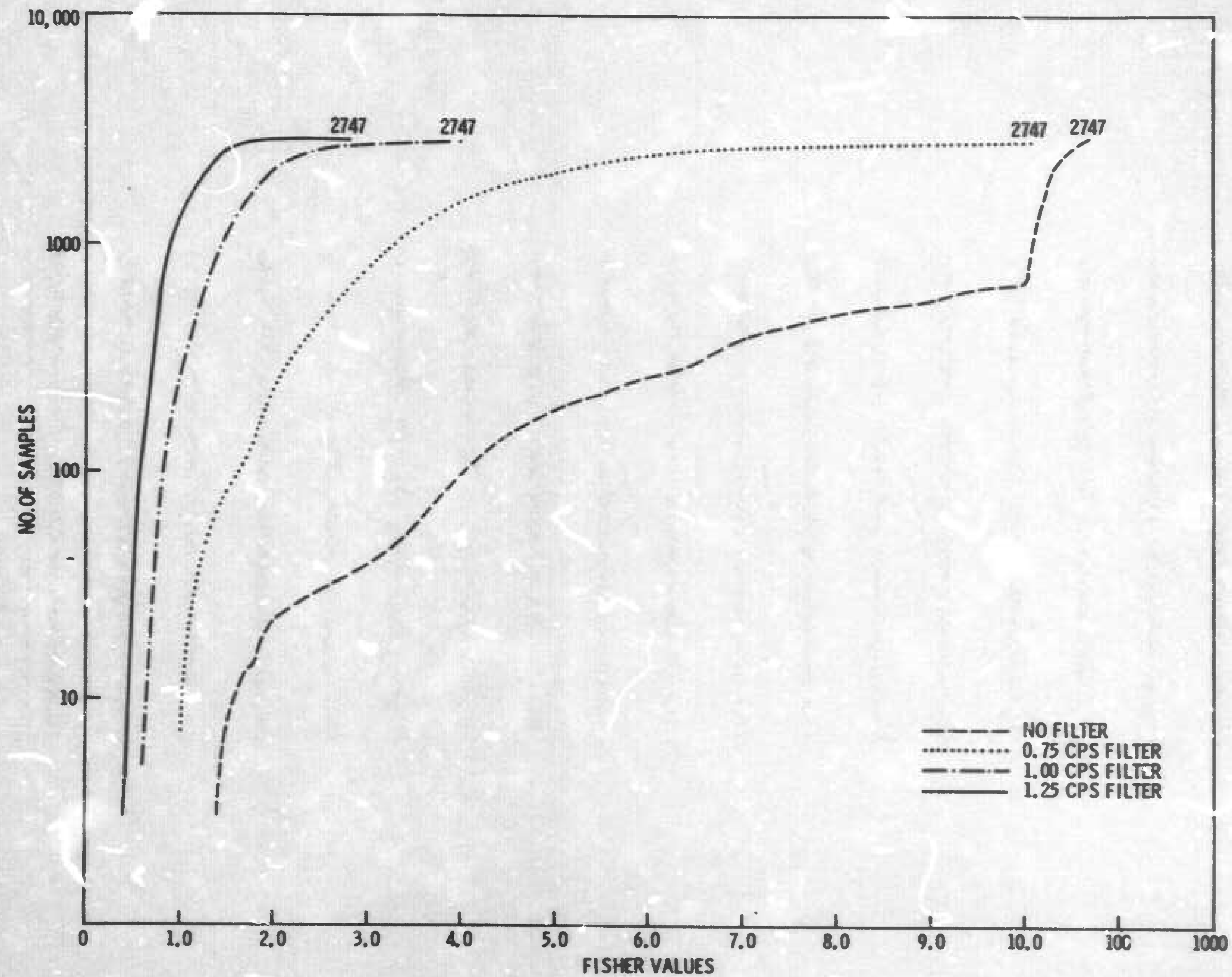


Figure V-18. Cumulative Distribution for Fisher Statistic for CPO 1963 19-Channel Noise Sample

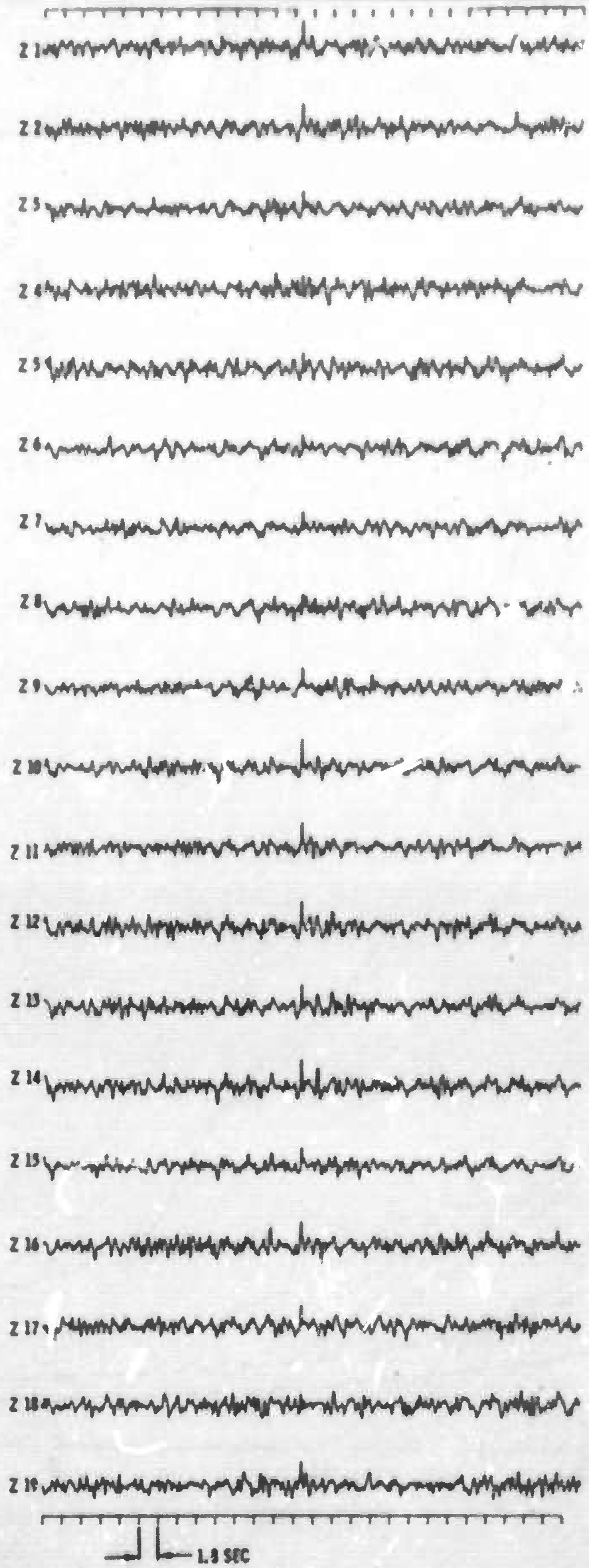


Figure V-19 CPO Theoretical Noise Sample Plus Wavelet for the Infinite Velocity Case

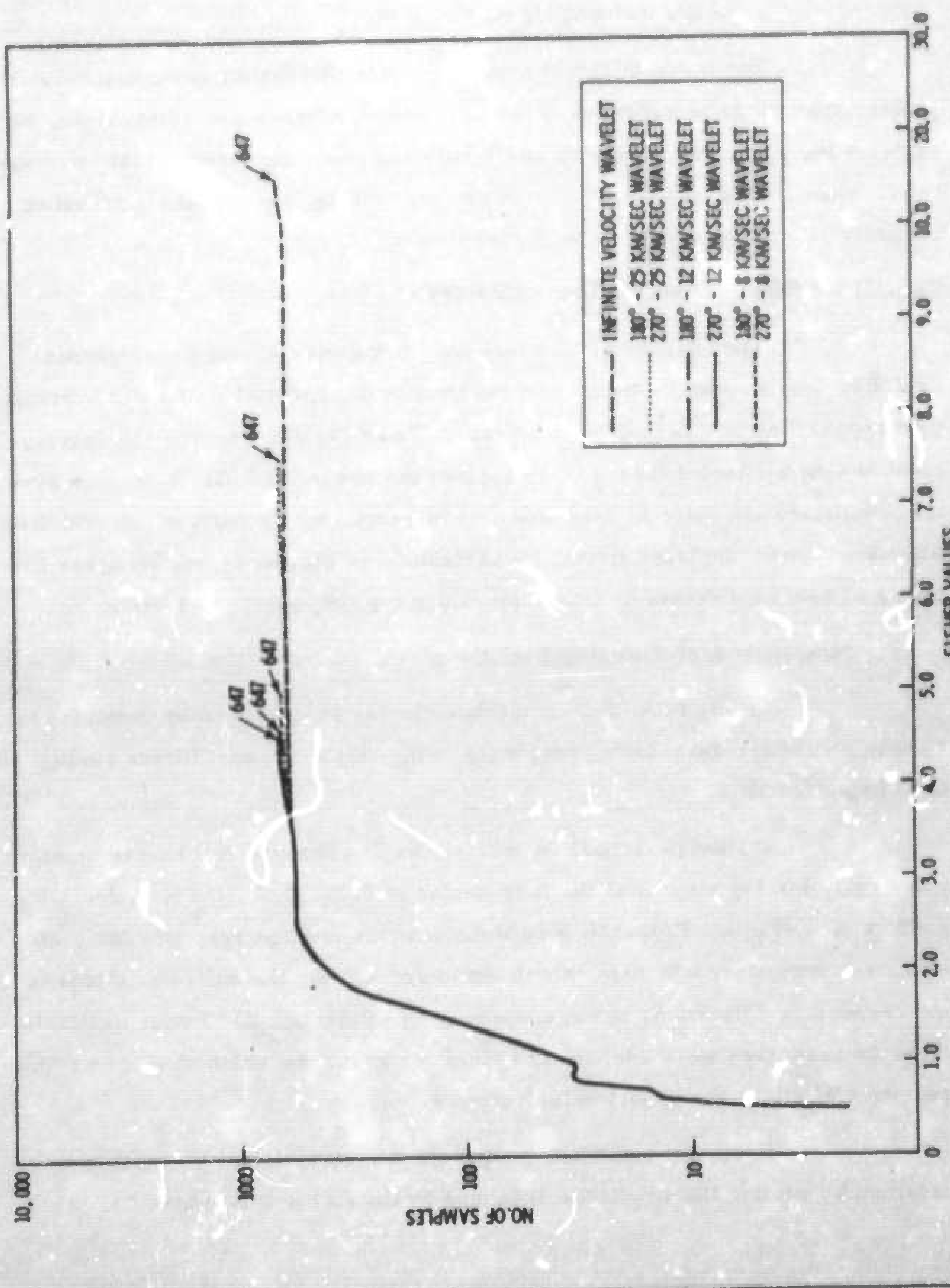


Figure V-20. Cumulative Distribution for Fisher Statistic for Theoretical Signal Wavelets

- The size of the Fisher values rapidly increase as the velocity of the incident signal increases.

Decrease in signal output level for the Fisher computation is greater than would be expected on the basis of array response comparison, and explains the Fisher property of significantly suppressing quarry blast information. When compared with Wiener power processing, the signal suppression property is more severe for the Fisher output.

C. IMPROVEMENT OF VISUAL DATA DISPLAY

The purpose of this task was to improve visual Develocorder data displays in order to aid station analysts in interpretation of event arrivals. Two approaches to this task were studied. The first of these was the development of single-channel filters to be applied on-line in the MCF to remove system amplitude and velocity responses. The second was a study of several display techniques. Included were both variable area playbacks and bandpass filtering of recorded events to determine which type of system was best.

1. Single-Channel Filtering Technique

In this task, the visual data display is improved by removing the system amplitude and velocity responses using single-channel filters on-line at CPO using the MCF.

Station personnel calibrated the Z-1 through Z-10 seismometers twice daily for 1-½ months at the frequencies of 0.25, 0.50, 0.75, 1.00, 1.50, 2.00, and 3.00 cps. From these calibrations, an average response for each of the seismometers was then calculated to account for the daily variations in the responses. Since only the responses for Z-1 through Z-10 were available, these 10 responses were averaged to yield one response which should be representative of all 19 short-period instruments.

From the amplitude response, a system velocity response was obtained by scaling the amplitude response by the factor $2\pi f$, where f is the

frequency. To obtain the response of the filters which would remove the amplitude and velocity responses, reciprocals of these responses were calculated; these are displayed in Figures V-21 and V-22, respectively.

The filters that were developed are also shown in Figures V-21 and V-22 for the amplitude and velocity removal techniques, respectively. The filters were 39 and 200 points in length; or 1.95 sec and 10.0 sec. The conclusions drawn from these figures are that filters of at least 200 points in length would be required to successfully perform this task, and that these filters would probably still not give a good approximation of the desired results.

Due to the fact that extremely long filters are necessary for this task and these filters require more core space in the MCF than was available under the programing mode, this method of approaching the task was discontinued.

2. Variable Display Technique

Several different playback techniques were analyzed to determine which technique or combination of techniques best aided station analysts in picking event arrival times, event first-motion directions and in identifying event phases.

Results showed a good technique in the identification of first arrivals and phase detection is a combination of variable area playbacks with wiggly traces and bandpass filtering (0.8 to 1.8 cps). Figure V-23 shows a small earthquake recorded at CPO on 9 May 1963 from the Pacific Ocean at an approximate distance of 40°. "A" shows the event as recorded at CPO, "B" shows the variable area wiggly trace playback of the event and "C" shows the same data as as "B" except the event has been filtered by a bandpass filter with a 0.8 to 1.8 cps passband.

This figure clearly shows the advantage of this method in the analysis and reporting of small earthquakes. Number 1 shows the first arrivals

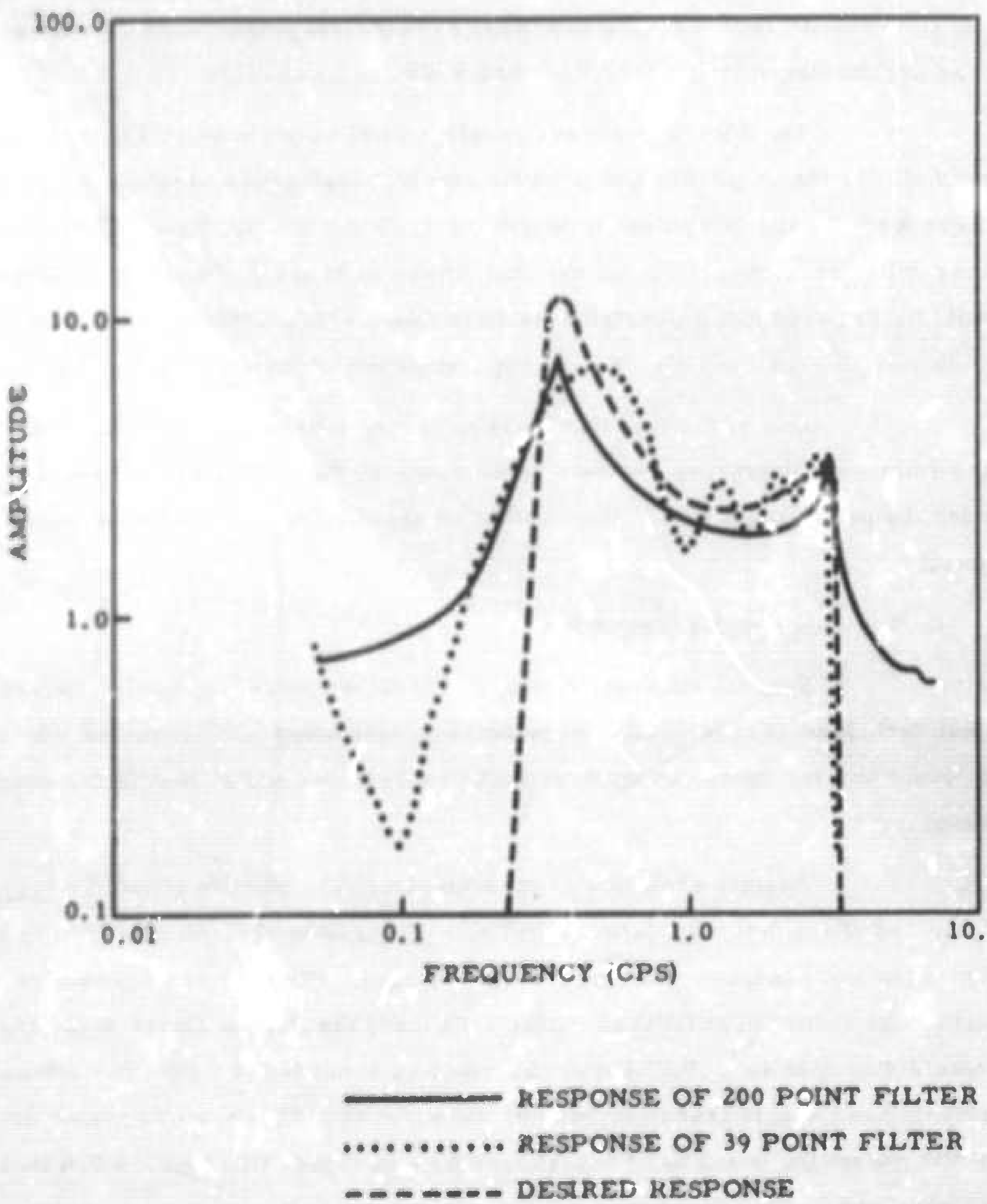


Figure V-21. Responses of the CPO Amplitude Removal Filters

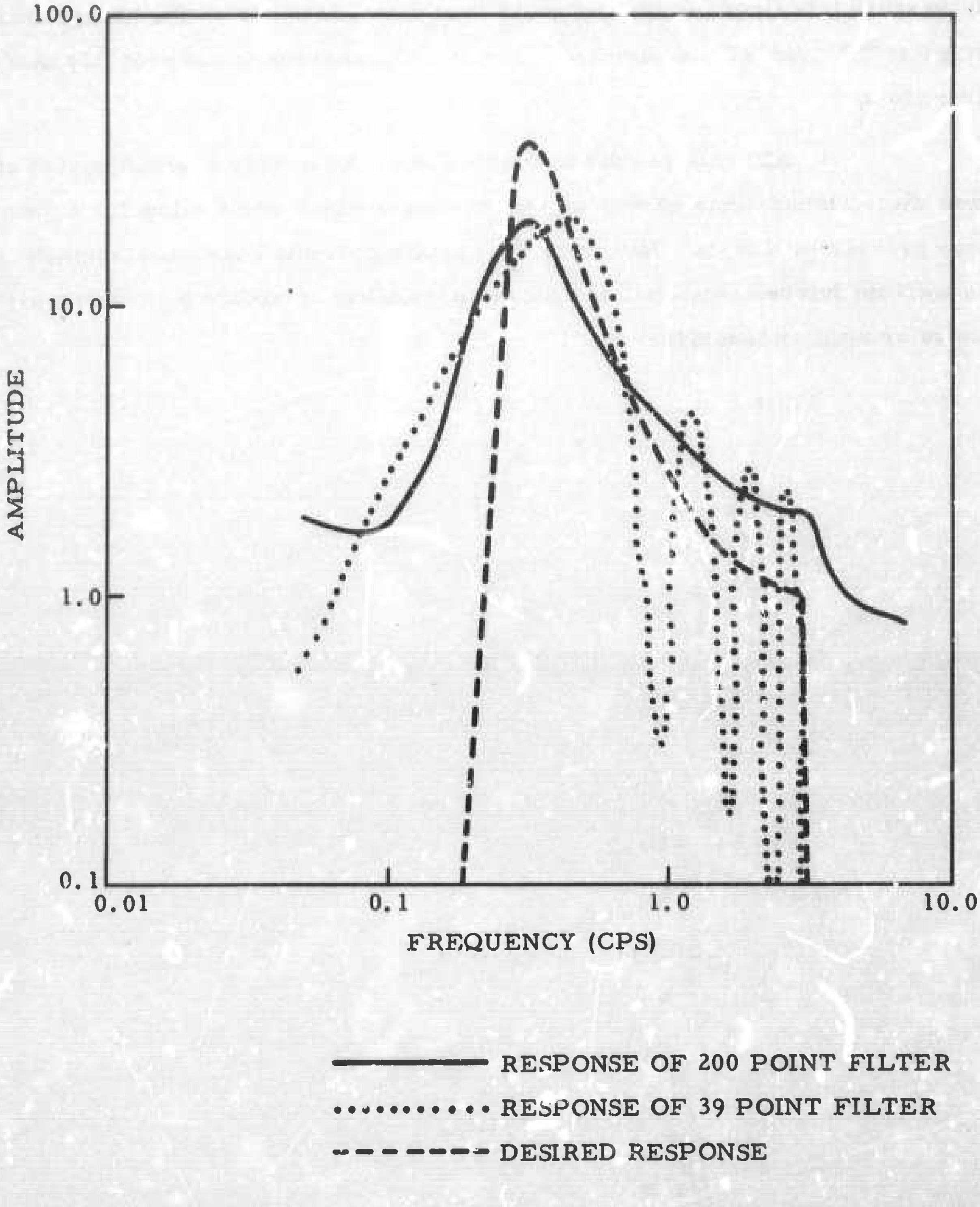
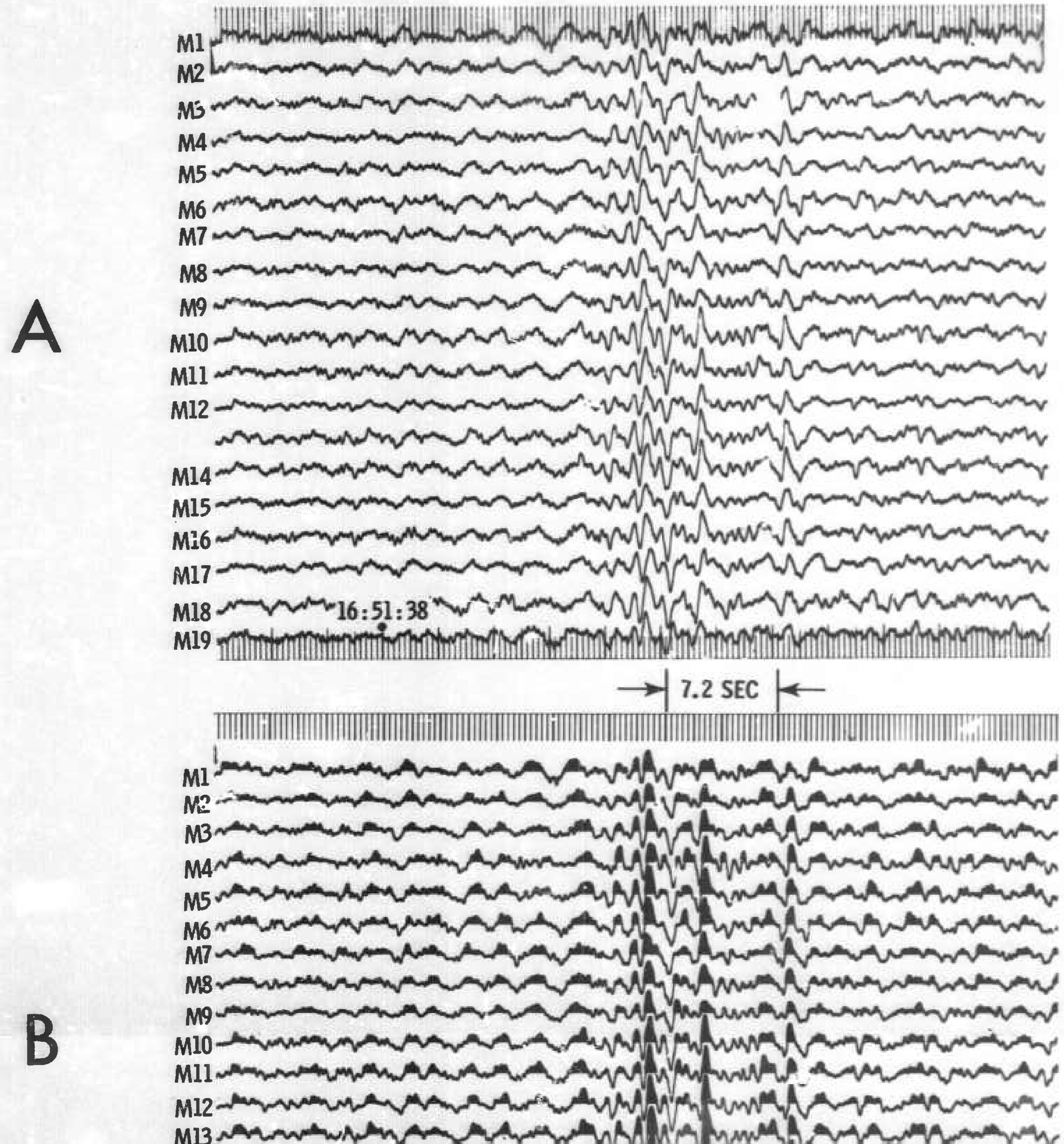


Figure V-22. Responses of the CPO Velocity Removal Filters

of the event, while 2, 3 and 4 point out later phases of the event. Of special interest in this figure is the way that phase 4 stands out from the background in parts "B" and "C" as compared to part "A", where it would probably not be identified.

Although results of this technique were very promising, the study was discontinued since no method was available which would allow for easy on-line processing of data. However, the results p[illegible]nted are encouraging enough to warrant future investigations into the possibility of on-line processing using these or similar techniques.

1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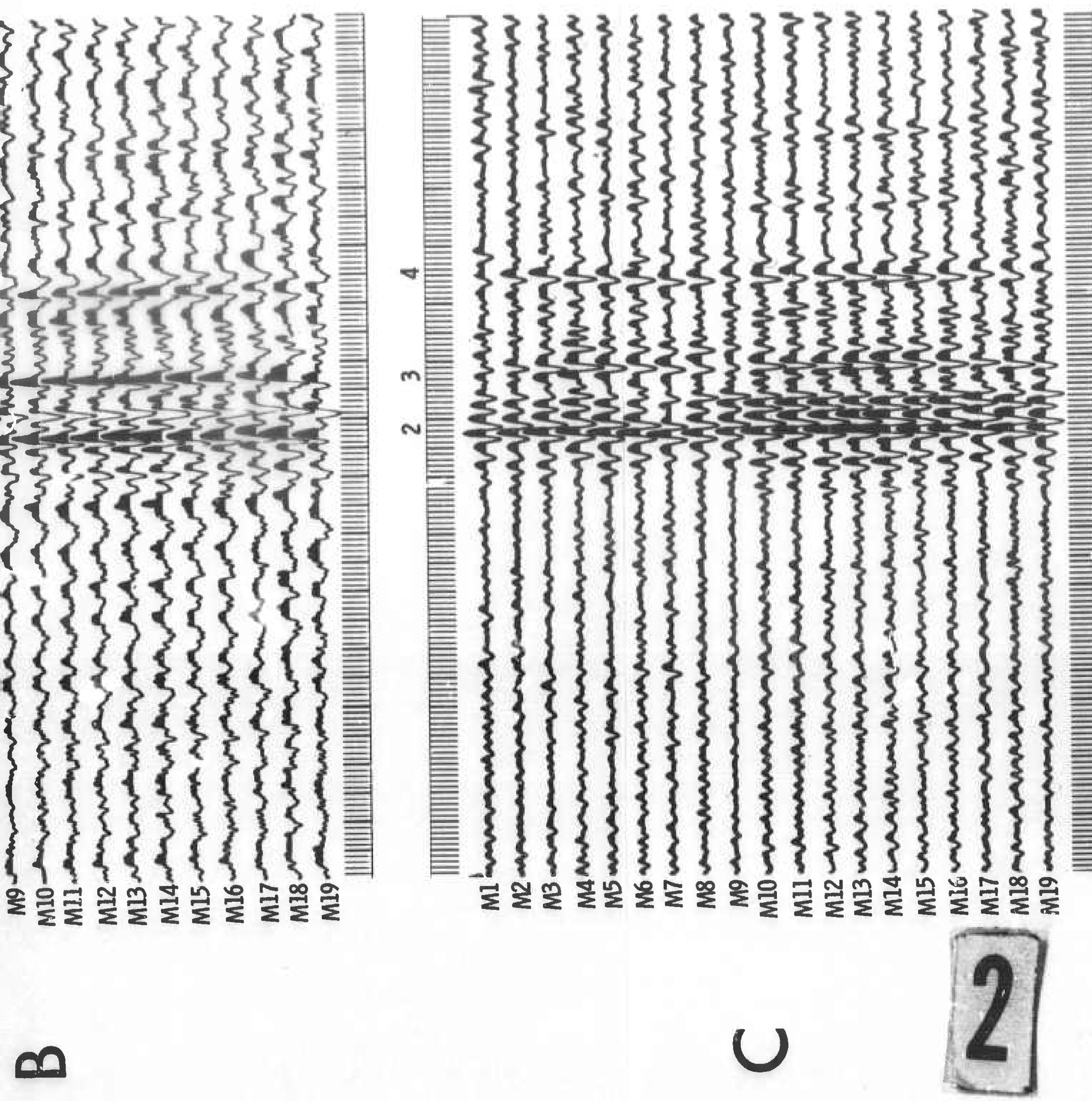

Figure V-23. CPO Event, 9 May 1963: (A) Straight Playback· (B) Variable Area, Wiggly Trace; (C) Variable Area Wiggly Trace, Pass-band Filtered 0.8 to 1.8 cps

SECTION VI
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6. Texas Instruments Incorporated, 1967: CPO Ambient Noise Study, CPO Spec. Rpt. 1, Contract AF 33(657)-14648, 27 June.

APPENDIX

CPO REPORTS

CONTRACT AF 33(657)-14648

APPENDIX

PUBLISHED CPO REPORTS

CONTRACT AF 33(657)-14648

This appendix lists the reports published under this contract and gives a short description of each.

1. CPO Quarterly Report No. 1, 15 August 1965 (Research from 1 May 1965 through 31 July 1965)
2. CPO Quarterly Report No. 2, 15 November 1965 (Research from 1 August 1965 through 31 October 1965)
3. Instruction Manual, 15 March 1966 - Operation and Maintenance of CPO Multichannel Filter System
4. CPO Quarterly Report No. 3, 29 March 1966 (Research from 1 November 1965 through 31 January 1966)
5. CPO Annual Report No. 1, 15 September 1966 (Research from 1 May 1965, through 30 April 1966)
6. CPO Special Report No. 2, 21 September 1966, Prototype Digital Multichannel Filter System (Digital multichannel filter system including the design philosophy and various system tests)
7. CPO Quarterly Report No. 4, 28 October 1966 (Research from 1 May 1966 through 31 July 1966)
8. CPO Quarterly Report No. 5, 9 November 1966 (Research from 1 August through 31 October 1966)
9. Instruction Manual, 1 January 1967 - Operation and Maintenance of the Auxiliary Processor
10. CPO Quarterly Report No. 6, 15 February 1967 (Research from 1 November 1966 through 31 January 1967

11. CPO Special Report No. 3, June 1967 - Auxiliary Processor Simulator

12. CPO Special Report No. 1, 27 June 1967, CPO Ambient Noise Study

13. CPO Special Report No. 4, 30 June 1967, Evaluation of the CPO Multichannel Filter Processor

14. CPO Special Report No. 5, 30 June 1967, Evaluation of the CPO Auxiliary Processor

15. CPO Quarterly Report No. 7, 30 June 1967 (Research from 1 February 1967 through 30 April 1967)

16. CPO Annual Report No. 2, 30 June 1967 (Research from 1 May 1966 through 30 April 1967)

1. CPO Quarterly Report No. 1

The first quarterly progress report reviews the analysis, engineering and research tasks which have been performed or initiated during May, June and July of 1965.

During the first three months of operation, routine analysis and operation of the station continued and specific research studies on ambient noise, signal-to-noise ratios and detection capability were initiated. In addition, a digital multichannel filter unit was being built by TI for installation early in 196′.

2. CPO Quarterly Report No. 2

The second quarterly progress report reviews the analysis, engineering and research tasks which were performed or initiated during August, September and October of 1965.

During the second 3-month period of the contract, routine operations and analysis continued at CPSO. The research tasks involving ambient noise studies, signal-to-noise ratio studies and detection capability advanced smoothly.

3. Instruction Manual - Operation and Maintenance of CPO Multichannel Filter System

This instruction book contains operation and maintenance information for the CPO multichannel filter system.

The multichannel filter system uses digital processing techniques for simultaneous real-time filtering of several inputs through several filters. Since it is digital, the system is highly reliable, requires no tuning, can operate unattended over long periods of time, and any or all of its filter coefficients can easily be changed by programing the magnetic core memory from punched paper tape or from control panel switches. Subject to total memory size limitations, the system can be programed to accept analog inputs from up to 32

sources, sample each input 20 times/sec, process up to five filters/channel, store up to 512 pts/filter, and beam-steer one of the filters in up to ten different directions.

4. CPO Quarterly Report No. 3

This report reviews the operational and research work conducted by Texas Instruments Incorporated during November and December 1965 and January 1966 on the Cumberland Plateau Seismological Observatory (CPO) Operations and Research contract.

During the third quarterly report period, operation of the observatory continued on a routine basis. High-quality seismic film and magnetic tape data were recorded on an around-the-clock schedule with minimum station down-time. Also, improvement in the overall observatory maintenance configuration was obtained by continuing sound station preventative maintenance procedures routinely.

Normal station-conducted analysis and research tasks were continued on schedule at CPO.

The associated CPO research tasks progressed smoothly and, in most cases, neared completion.

5. CPO Annual Report No. 1

This annual report reviews the analysis, engineering and research tasks which have been performed during the first contract year, May 1965 through April 1966.

During the 1-yr period, routine operations and analysis continued at CPO, and research tasks were performed on travel-time studies and the cataloging of events by station personnel. Research at the Dallas facility included construction and installation of a digital multichannel filter processor (DMCF) plus associated research tasks, and ambient noise study and signal-to-noise ratio studies.

6. CPO Special Report No. 2 - Prototype Digital Multichannel Filter System

Contract AF 33(657)-14648 was directed in part toward development of a prototype digital multichannel filter system for use in the on-line processing of seismometer array data at the Cumberland Plateau Seismological Observatory (CPO).

This special report documents the digital multichannel filter system. A summary of the design philosophy is included, and results of various system tests are presented as appendixes.

7. CPO Quarterly Report No. 4

This report reviews the operations and research work conducted by Texas Instruments Incorporated during May, June and July 1966 on the Cumberland Plateau Observatory (CPO) contract. Efforts during this period were directed toward routine observatory operations, Dallas- and station-conducted research tasks and design and construction of a detection and identification digital processor.

Operation of CPO during the reported period continued on a routine basis. Magnetic tape and film data were high quality. The overall observatory maintenance configuration was good, and minimum station down-time was reported as a result of a sound, continuing preventive maintenance program.

Research activities during the quarter concentrated on evaluation of the MCF processor, ambient noise studies and detection processor simulation. Data are presented which demonstrate a significant increase in station detection capability as a result of on-line MCF processing.

As of 31 July, construction of the auxiliary processor was 42 percent complete, and the program was on schedule.

8. CPO Quarterly Report No. 5

This report reviews the operations and research work conducted by Texas Instruments Incorporated during August, September and October 1966

on the Cumberland Plateau Observatory (CPO) contract. Efforts during the quarter were directed toward routine observatory operations, Dallas- and station-conducted research tasks and construction and checkout of a detection and identification digital processor.

Operation of CPO during the reporting period continued on a routine basis. The overall observatory maintenance configuration remained good with minimum station down-time resulting from a continual preventive maintenance program. Magnetic tape and film data were also high-quality.

Research activities during this quarter concentrated on evaluation of the MCF processor, ambient noise studies, detection processor research and a study to improve visual data displays. Data are presented to demonstrate the increase in station detection capability as a result of on-line MCF processing.

As of 31 October, construction of the auxiliary processor was complete, the basic MCF was modified to interface with the auxiliary processor and separate checkouts of the two units were completed. The next phase was to interface the units and conduct system checkout.

9. Instruction Manual - Operation and Maintenance of the Auxiliary Processor

This instruction manual contains operation and maintenance information for the addition of an Auxiliary Processor to the CPO multichannel filter system. The Auxiliary Processor provides the capability of performing supplementary processes without increasing the memory capacity or slowing the normal filtering processes of the CPO multichannel filter system. The additional processes which the Auxiliary Processor provides are called the Fisher process, United Kingdom process and the MCF Power process. In addition to the new processing capability, the Auxiliary Processor provides digital threshold detectors on the Fisher and the MCF Power outputs.

The Auxiliary Processor monitors the CPO multichannel filter processor, interrupts intermittently for data storage and performs its routines utilizing the CPO multichannel filter memory, multiplier, output registers, and several other circuits. Control signals, basic clocks and dc voltage, excluding digital-to-analog converter power, for the Auxiliary Processor is supplied from the CPO multichannel filter system.

The Auxiliary Processor provides digital-to-analog converters for one Fisher output, two United Kingdom outputs and four MCF Power outputs.

10. CPO Quarterly Report No. 6

Work conducted by Texas Instruments Incorporated from November 1966 through January 1967 under the Cumberland Plateau Observatory (CPO) contract is reviewed in this quarterly report. Efforts during this quarter were directed toward observatory operations, hardware construction and on-line implementation, and Dallas-based supporting research.

Observatory operations and additional data on the "coefficient loss problem" which previously existed in the MCF processor are discussed. In addition to the rapid-stop monitor for detecting marginal input power, modifications to the processor gounding system were necessary to eliminate entirely the problem of coefficient losses.

Research activities, including ambient noise studies, visual data display improvement and MCF processor evaluation, are reviewed. Data are presented which demonstrate the continued time-stationarity of the ambient noise field over a 2-yr period, thus indicating that, in at least general terms, MCF operators developed under previous efforts are appropriate for present application in the MCF processor.

Design, construction and installation of the auxiliary detection and identification processor were completed on 30 December. A description of the system and a discussion of the on-line implementation and operating

parameters are presented. Also included is a discussion of the evaluation procedures and goals and an outline of the supporting Dallas-based research.

11. CPO Special Report No. 3 - Auxiliary Processor Simulator

The digital MCF-Auxiliary Processor was simulated by a computer program to facilitate the checkout of the processor and to study various operating parameters. The program follows the logic of the processor as much as possible and contains the following main sections: basic MCF filter routine, beam-steer routine, Wiener power processor, UK processor, Fisher output controller, and divide routine.

12. CPO Special Report No. 1 - CPO Ambient Noise Study

A thorough and comprehensive analysis of the ambient seismic noise field existing at the Cumberland Plateau Observatory (CPO) located E-SE of McMinnville, Tennessee, was the partial goal of Contract AF 33(657)-14648. Included in this investigation was the analysis of:

- Absolute noise power density spectra
- Spatially organized low velocity noise
- Spatially organized high velocity noise

The purpose of this special report is to summarize the results of this analysis and present in detail the data used to derive the presented conclusions. The data for this analysis covers the period January to March 1963 and 1 May 1965 through 31 October 1966.

13. CPO Special Report No. 4 - Evaluation of the CPO Multichannel Filter Processor

As a part of the first year's effort on Contract AF 33(657)-14648, Texas Instruments Incorporated designed, fabricated and installed a digital multichannel filter system at the Cumberland Plateau Seismological Observatory.

Preliminary evaluation of the processor during the first contract

year, presented in CPO Annual Report No. 1, showed a 21-percent increase of reported events at CPO after the installation of the processor in March 1966 as compared with February 1966. Station personnel during the first year reported that the MCF aided them in clearly identifying events which they otherwise would not have detected.

An extensive evaluation of the system as a detection device was performed while the system was on-line during the second contract year. The purpose of this report is to review this evaluation of the increase in detection capability and amount of noise rejection, to present recommendations regarding future operation of the system and to summarize the hardware performance.

14. CPO Special Report No. 5 - Evaluation of the CPO Auxiliary Processor

In addition to routine operation of the Cumberland Plateau Seismological Observatory, considerable applied research was conducted under Contract AF 33(657)-14648 to advance the understanding of array processing technology applicable to small seismic arrays used in the nuclear detection and classification problem. During the last project year, under VT/6704 on-line real-time detection and identification processing was implemented and evaluated at CPO for the primary purpose of studying automatic detection processing.

On-line processing was implemented using the CPO Auxiliary Processor which computes two classes of detection outputs, the Fisher analysis-of-variance statistic and the Wiener power statistic, and one class of identification output, the United Kingdom technique. The detection outputs were compared on-line against a fixed signal threshold level for automatic detection. From this comparison a continuous real-time "yes-no" output was provided for signal. This output, along with the detection and identification data, was recorded on Develocorder film.

Contained in this report is a brief description of the digital processing hardware and results of the hardware evaluation. Conclusions, as well

as supporting data regarding the evaluation of on-line detection and identification processing, are presented. Also, results from off-line supporting applied research are covered.

15. CPO Quarterly Report No. 7

This report reviews the work conducted by Texas Instruments Incorporated under the CPO Operations and Research Contract during the final contract quarter — 1 February 1967 through 30 April 1967. Activities during this period were directed primarily toward routine observatory operation, completion of all research tasks and preparation of special reports covering this work, and transfer of the observatory facilities and equipment.

Presented is a description of observatory operations conducted during the quarter. Results of routine analysis and a discussion of preventive and remedial maintenance required during the period are included. Research work conducted during this quarter is outlined and summarized. Details of the noise analysis, MCF evaluation and Auxiliary Processor evaluation were presented in special reports covering each of these areas. Also covered is the transfer of CPO facilities and equipment. For future references, lists of equipment, facilities and expendable supplies which were transferred are provided in the appendixes. Disposition of each of these items is included.

16. CPO Annual Report No. 2

Since May 1965, Texas Instruments Incorporated had overall responsibility for operation of the Cumberland Plateau Seismological Observatory. In conjunction with this, TI conducted research and investigation tasks directed toward the development and application of sophisticated processing techniques designed to enhance present knowledge of processing small diameter seismic arrays for teleseismic event detection. Included in these tasks was the design, fabrication, operation and evaluation of sophisticated on-line digital processing hardware which accomplishes Wiener multichannel signal extration filtering, automatic event detection and classification processing.

This work was conducted under the technical direction of the Air Force Technical Applications Center and was sponsored by the Advanced Research Projects Agency as part of the VELA UNIFORM program.

This annual report reviews the station operation, research and hardware development and evaluation conducted during the second contract year under AFTAC Project VT/6704 for the period May 1966 through April 1967. Work accomplished during the first contract year (AFTAC Project VT/5054) was documented in CPO Annual Report No. 1 and is reviewed and summarized in this report where necessary for continuity.

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3. REPORT TITLE

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4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

Annual Report

5. AUTHOR(S) (Last name, first name, initial)

Edwards, James P. III; Benno, Stephen A.; Bauer, Ronald D.; Creasey, Geraldine; Rekicta, Thomas W.

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13. ABSTRACT

Under AFTAC Project VT/6704 Texas Instruments Incorporated has had overall responsibility for the operation of the Cumberland Plateau Observatory during the period May 1966 through April 1967. Work under this project has been a continuation of the previous years effect under Project VT/5054 and has been primarily directed toward improving the use of small diameter seismic arrays in the teleseismic event detection problem. During this last year the feasibility and effectiveness of on-line automatic detection processing was investigated through the evaluation of the CPO Auxiliary Processor. This unit- a digital computing device fabricated during late 1966 -interfaces with the CPO processor. Other tasks included the continued evaluation of the MCF processor to determine the impact of Wiener signal extraction processing on the station detection capability, the continued multidimensional analysis of the CPO ambient noise field to verify noise properties affecting performance of the MCF processor, and the investigation of techniques designed to enhance visual presentation of seismic data.

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14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Cumberland Plateau Observatory						
CPO Auxiliary Processor						
Small Diameter Seismic Arrays						
Teleseismic Event Detection						
On-Line Automatic Detection Processing						
CPO Multichannel Filter Processor						
Wiener Signal Extraction Processing						

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parameters are presented. Also included is a discussion of the evaluation procedures and goals and an outline of the supporting Dallas-based research.

11. CPO Special Report No. 3 - Auxiliary Processor Simulator

The digital MCF-Auxiliary Processor was simulated by a computer program to facilitate the checkout of the processor and to study various operating parameters. The program follows the logic of the processor as much as possible and contains the following main sections: basic MCF filter routine, beam-steer routine, Wiener power processor, UK processor, Fisher output controller, and divide routine.

12. CPO Special Report No. 1 - CPO Ambient Noise Study

A thorough and comprehensive analysis of the ambient seismic noise field existing at the Cumberland Plateau Observatory (CPO) located E-SE of McMinnville, Tennessee, was the partial goal of Contract AF 33(657)-14648. Included in this investigation was the analysis of:

- Absolute noise power density spectra
- Spatially organized low velocity noise
- Spatially organized high velocity noise

The purpose of this special report is to summarize the results of this analysis and present in detail the data used to derive the presented conclusions. The data for this analysis covers the period January to March 1963 and 1 May 1965 through 31 October 1966.

13. CPO Special Report No. 4 - Evaluation of the CPO Multichannel Filter Processor

As a part of the first year's effort on Contract AF 33(657)-14648, Texas Instruments Incorporated designed, fabricated and installed a digital multichannel filter system at the Cumberland Plateau Seismological Observatory.

Preliminary evaluation of the processor during the first contract

year, presented in CPO Annual Report No. 1, showed a 21-percent increase of reported events at CPO after the installation of the processor in March 1966 as compared with February 1966. Station personnel during the first year reported that the MCF aided them in clearly identifying events which they otherwise would not have detected.

An extensive evaluation of the system as a detection device was performed while the system was on-line during the second contract year. The purpose of this report is to review this evaluation of the increase in detection capability and amount of noise rejection, to present recommendations regarding future operation of the system and to summarize the hardware performance.

14. CPO Special Report No. 5 - Evaluation of the CPO Auxiliary Processor

In addition to routine operation of the Cumberland Plateau Seismological Observatory, considerable applied research was conducted under Contract AF 33(657)-14648 to advance the understanding of array processing technology applicable to small seismic arrays used in the nuclear detection and classification problem. During the last project year, under VT/6704 on-line real-time detection and identification processing was implemented and evaluated at CPO for the primary purpose of studying automatic detection processing.

On-line processing was implemented using the CPO Auxiliary Processor which computes two classes of detection outputs, the Fisher analysis-of-variance statistic and the Wiener power statistic, and one class of identification output, the United Kingdom technique. The detection outputs were compared on-line against a fixed signal threshold level for automatic detection. From this comparison a continuous real-time "yes-no" output was provided for signal. This output, along with the detection and identification data, was recorded on Develocorder film.

Contained in this report is a brief description of the digital processing hardware and results of the hardware evaluation. Conclusions, as well

as supporting data regarding the evaluation of on-line detection and identification processing, are presented. Also, results from off-line supporting applied research are covered.

15. CPO Quarterly Report No. 7

This report reviews the work conducted by Texas Instruments Incorporated under the CPO Operations and Research Contract during the final contract quarter — 1 February 1967 through 30 April 1967. Activities during this period were directed primarily toward routine observatory operation, completion of all research tasks and preparation of special reports covering this work, and transfer of the observatory facilities and equipment.

Presented is a description of observatory operations conducted during the quarter. Results of routine analysis and a discussion of preventive and remedial maintenance required during the period are included. Research work conducted during this quarter is outlined and summarized. Details of the noise analysis, MCF evaluation and Auxiliary Processor evaluation were presented in special reports covering each of these areas. Also covered is the transfer of CPO facilities and equipment. For future references, lists of equipment, facilities and expendable supplies which were transferred are provided in the appendixes. Disposition of each of these items is included.

16. CPO Annual Report No. 2

Since May 1965, Texas Instruments Incorporated had overall responsibility for operation of the Cumberland Plateau Seismological Observatory. In conjunction with this, TI conducted research and investigation tasks directed toward the development and application of sophisticated processing techniques designed to enhance present knowledge of processing small diameter seismic arrays for teleseismic event detection. Included in these tasks was the design, fabrication, operation and evaluation of sophisticated on-line digital processing hardware which accomplishes Wiener multichannel signal extration filtering, automatic event detection and classification processing.

This work was conducted under the technical direction of the Air Force Technical Applications Center and was sponsored by the Advanced Research Projects Agency as part of the VELA UNIFORM program.

This annual report reviews the station operation, research and hardware development and evaluation conducted during the second contract year under AFTAC Project VT/6704 for the period May 1966 through April 1967. Work accomplished during the first contract year (AFTAC Project VT/5054) was documented in CPO Annual Report No. 1 and is reviewed and summarized in this report where necessary for continuity.

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13. ABSTRACT
Under AFTAC Project VT/6704 Texas Instruments Incorporated has had overall responsibility for the operation of the Cumberland Plateau Observatory during the period May 1966 through April 1967. Work under this project has been a continuation of the previous years effect under Project VT/5054 and has been primarily directed toward improving the use of small diameter seismic arrays in the teleseismic event detection problem. During this last year the feasibility and effectiveness of on-line automatic detection processing was investigated through the evaluation of the CPO Auxiliary Processor. This unit- a digital computing device fabricated during late 1966 -interfaces with the CPO processor. Other tasks included the continued evaluation of the MCF processor to determine the impact of Wiener signal extraction processing on the station detection capability, the continued multidimensional analysis of the CPO ambient noise field to verify noise properties affecting performance of the MCF processor, and the investigation of techniques designed to enhance visual presentation of seismic data.

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